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YIELD EFFECTS ON THE RESPONSE OF A BURIED BLAST SHELTER

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YIELD EFFECTS ON THE RESPONSE OF A BURIED BLAST SHELTER

by

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Structures Laboratory

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The Federal Emergency Management Agency has tasked the US Army Engineer Division, Huntsville, to design a Keyworker blast shelter. In conjunction with this project, the US Army Engineer Waterways Experiment Station conducted a series of tests to investigate the effects of variations in weapon yield and the absence of wall stirrups on the structural response of a reinforced concrete box-type shelter.

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PREFACE

The research reported herein was sponsored by the Federal Emergency Management Agency (FEMA) through the US Army Engineer Huntsville Division.

Construction and testing were conducted by personnel of the Structures Laboratory (SL), US Army Engineer Waterways Experiment Station (WES), under the general supervision of Mr. Bryant Mather, Chief, SL, and Mr. J. T. Ballard, Assistant Chief, SL. Chief of the Structural Mechanics Division (SMD), SL, during this investigation was Dr. J. P. Balsara. The project was managed by Dr. S. A. Kiger, SMD. The field tests were supervised by Messrs. R. L. Holmes, T. R. Slawson, and S. C. Woodson and were instrumented by Messrs. H. P. Parks and W. C. Strahan, Jr., Instrumentation Services Division, WES. This report was prepared by Mr. Slawson, Ms. S. B. Garner, and Mr. Woodson, SMD, SL, and was edited by Ms. Janean C. Shirley, Publications and Graphic Arts Division, WES. Mr. Tom Provenzano, FEMA, was the Program Monitor.

Director of WES was COL Allen F. Grum, USA. Technical Director was Dr. Robert W. Whalin.

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CONVERSION FACTORS, NON-SI TO SI (METRIC)
UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
cubic feet	0.02831685	cubic metres
feet	0.3048	metres
g's (standard free fall)	9.806650	metres per second squared
grains per foot	0.2125948	grams per metre
horsepower (550 foot-pounds (force) per second)	745.6999	watts
inches	2.54	centimetres
kilotons (nuclear equivalent of TNT)	4.184	terajoules
kips (force) per square inch	6.894757	megapascals
megatons (nuclear equivalent of TNT)	4.184	petajoules
pounds (force)	4.448222	newtons
pounds (force) per square inch	6.894757	kilopascals
pounds (mass) per cubic foot	16.01846	kilograms per cubic metre

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

At the initiation of this study, civil defense planning called for the evacuation of nonessential personnel to safe (low-risk) host areas during a time of crisis and the construction of blast shelters to protect key workers remaining behind. The Federal Emergency Management Agency (FEMA) has tasked the US Army Engineer Division, Huntsville (HND), to design a 100-man Keyworker blast shelter. The shelter has been designed to resist a peak overpressure of 50 psi[1] from a 1-MT nuclear weapon. Two configurations have been considered: (1) an underground shelter buried under 4 feet of backfill and (2) an above-ground shelter enclosed in a soil berm. One-quarter scale models of the underground structure have been constructed at the US Army Engineer Waterways Experiment Station (WES) and tested in a simulated overpressure from a 16-KT nuclear weapon. The design and testing of the 1/4-scale structures are discussed by Slawson et al. (Reference 1).

Because of the large number of shelters to be constructed, efficient and economic use of materials and labor is an important consideration in the design of the shelter. The original design included shear stirrups between the two principal reinforcement steel mats in the roof and walls. Static tests were conducted on roof slabs with and without stirrups (References 2 and 3), and it was concluded that the benefits of the roof stirrups were negligible and did not justify installation costs. One of the objectives of the present test is to investigate the effects of eliminating wall stirrups.

In June 1985, MINOR SCALE, a 9.6-million-pound high-explosive (HE) event simulating an 8-KT nuclear surface burst took place at White Sands Missile Range, N. Mex. Structures tested in MINOR SCALE included one full-scale buried Keyworker blast shelter and two 1/4-scale berm configuration shelters. In the MINOR SCALE Event the full-scale shelter was placed at a peak

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[1] A table of factors for converting non-SI to SI (metric) units of measurement is presented on page 5.

overpressure range designed to simulate the structural damage that would occur at a peak overpressure of 50 psi from a 1-MT nuclear surface burst. Prior to the MINOR SCALE Event, data were needed to confirm calculations of yield effects on buried structures.

1.2 OBJECTIVES

HE tests simulating overpressures from approximately 1/8- and 16-KT nuclear bursts were conducted on four 1/4-scale structural models. The main objective of the tests was to collect data to verify peak overpressures from 8-KT and 1-MT nuclear surface bursts that were calculated to cause the same structural response. The calculations were then used to determine the peak overpressure at which to place the prototype Keyworker blast shelter in the MINOR SCALE Event (an 8-KT nuclear simulation) to undergo the same structural response expected at the 50-psi peak overpressure level in a 1-MT nuclear surface burst.

These data will also be used to investigate the effects on structural response of reinforcement shear stirrups in the shelter walls.

1.3 SCOPE

The four structural models tested were approximately 1/4-scale models of the prototype Keyworker blast shelter and were similar to structures previously tested by Slawson et al. (Reference 1). Design modifications made as a result of the static and dynamic tests described in References 1, 2, and 3 were included in the construction of these models. Modifications included: the use of alternating bent-up and straight bars for principal reinforcement to ensure a ductile failure mode; a slight reduction in roof thickness (2-1/4 versus 2-1/2 inches); elimination of shear reinforcement steel in the roof and floor slabs; and single-leg stirrups rather than double-leg stirrups in the walls. One model had no wall stirrups. Four of the five models constructed were tested dynamically using the nuclear overpressure simulator discussed in Chapter 4. The test matrix is given in Table 1.1.

In previous tests, very little roof deflection resulted from the 16-KT weapon simulation at low overpressures (50-75 psi). Therefore, a 16-KT simulation at 130-psi overpressure was chosen as the baseline test to ensure enough structural response to evaluate the effects of a change in yield. The computer code VSBS (Reference 4) was used to predict deflections on the

prototype shelter from a 1-MT weapon at 130 psi and an 8-KT weapon at various overpressures. The calculations indicated that in order for an 8-KT weapon to cause the same structural response as a 1-MT weapon, the peak overpressure must be increased by about 50 percent. To verify the VSBS predictions, two of the boxes were tested at lower yield and higher overpressure.

Table 1.1. Test matrix.

Test	Element	Charge Density lb/ft^3	Comments
YE1	1	0.016	Baseline test
YE2	2	0.040	Low yield, high overpressure
YE3	5	0.016	Baseline weapon, no wall stirrups
YE4	3	0.036	Low yield, high overpressure

CHAPTER 2

CONSTRUCTION, INSTRUMENTATION, AND TEST CONFIGURATION

2.1 STRUCTURAL MODEL DETAILS

The test elements were approximately 1/4-scale reinforced concrete models of the FEMA Keyworker blast shelter. Open-ended boxes were used to simulate the one-way roof of the shelter. All elements had the following structural parameters:

1. Clear span of 33 inches
2. Clear height of 30 inches
3. Wall, roof, and floor thicknesses of 2-1/4 inches
4. Effective depth of 1.6 inches
5. Roof clear span-to-thickness ratio, L/T, of 14.8
6. Roof clear span-to-effective depth ratio, L/d, of 20.7
7. Tensile and compressive principal steel ratios of approximately $p = 0.012$ and $p' = 0.004$, respectively
8. Transverse steel ratio of approximately 0.002
9. 1/2-inch concrete cover over principal reinforcing

The principal steel consisted of heat-treated D3 deformed wire spaced at 2-7/16-inch centers. Alternating pairs of straight and bent bars were used in the roof and floor. Transverse reinforcement was heat-treated D1 deformed wire at 3-inch centers. Design yield strength for reinforcing was 60 ksi. Reinforcing details are shown in Figure 2.1.

Inside forms were assembled with an open end up, reinforcing mats and gage mounts were placed around forms, and outer forms were assembled around the reinforcing mats. Concrete was placed in a single pour by dropping and vibrating through the open end of the formwork. Additional vibrators were attached to the exterior of the forms to ensure that voids in the concrete were minimized. Boxes 1 and 2 were poured from a single batch, as were Boxes 3, 4, and 5.

Construction details are shown in Figures 2.2 through 2.5.

2.2 INSTRUMENTATION

Test data were recorded on two 32-channel Sangamo Sabre III FM magnetic tape recorders located in an instrumentation trailer approximately 800 feet

from the test site and later digitized at 200 kHz. A zero-time channel was included in each test to establish a common time reference for the data. Instrumentation layouts are shown in Figures 2.6 through 2.9. Table 2.1 lists the gages used in each test.

2.2.1 Airblast Pressure Gages

Six Kulite Model HKS-375 airblast pressure (BP) gages were located at ground level directly beneath the charge cavity. The range for the gages was 1,000 psi.

2.2.2 Soil Stress Gages

One soil stress gage was located 6 inches above the roof, three gages were located 1 inch above the roof, and five gages were located in the free field. Gages were Kulite SE Models LQV-080-8UHLR, with a range of 200 psi and LQV-080-8UH, with a range of 4,000 psi.

2.2.3 Accelerometers

Accelerations were measured at the midspan of the roof and floor and in the free field with Endevco Model 2262 accelerometers. Ranges varied from 400 to 2,000 g's.

2.2.4 Interface Pressure Gages

Four interface pressure gages were mounted on the box roof and one near the top of a wall. Gages were Kulite Model VM-750 with ranges of 200 and 500 psi.

2.2.5 Strain Gages

Six pairs of single-axis, metal film, 350-ohm strain gages were installed on the inside (EI) and outside (EO) of straight principal roof reinforcement. Gages were located at midspan, quarter-span, and near the supports. Four gages were installed on each of two bent principal reinforcing bars, and two pairs of gages were installed on the inside and outside wall reinforcing. The gages used were Micro-Measurement Model EA-06-250BF-350-W.

2.2.6 Deflection Gages

Position/displacement transducers were mounted at midspan and

quarter-span. The transducers measured deflection by means of a potentiometer which recorded extension and retraction of a cable attached to a spring inside the transducer. Each transducer was mounted on a steel framework welded to plates embedded in the floor structure, and the cable was attached to wire projecting from the roof. Transducers were Celesco Model PT-101-10-A-7559, with a 10-inch range.

2.3 TEST CONFIGURATION

The test bed configuration is shown in Figure 2.10. For each test, the test bed was excavated to a depth of 6 feet and backfilled to a depth of approximately 46 inches. A structure was then placed in the pit, and backfill was placed and compacted around the structure in 6-inch lifts. Cover was placed over the box and compacted in two 6-inch lifts.

The charge cavity size varied with each test. After the charge cavity was placed over the test bed, equally spaced strands of HE primacord were taped to the legs and horizontal bracing of the charge cavity, which was then covered with plywood. An uncompacted sand overburden was placed over the charge cavity to confine the blast pressure and thus simulate the pressure decay of a nuclear detonation. Cavity size, charge density, and depth of overburden were varied for each test, and are given in Table 2.2.

The explosive used in the test was pentaerythritol tetranitrate (PETN) made into 50-gr/ft detonating chord (primacord). All strands of primacord were spliced into a single bundle enclosing a blasting cap, so that all rows were detonated simultaneously starting at one end of the charge cavity. The cavity design ensured that the explosive was uniformly distributed and that the loading was due to a planar wave.

2.4 MATERIAL PROPERTIES

2.4.1 Concrete

The concrete mix was designed to have a 28-day compressive strength of 3,000 psi. The mix consisted of Type 1 portland cement obtained from a local commercial supplier, a natural siliceous sand fine aggregate, and a crushed limestone coarse aggregate with a 3/8-inch maximum diameter. Eleven 6-inch-diameter cylinders were taken from the first batch and nineteen from the second batch. One cylinder from Batch 1 was broken at 6 days, one at 28 days, four on the day of Test YE1, and five on the day of Test YE2. Four cylinders

from Batch 2 were broken at 28 days, four on the day of Test YE3, and three on the day of Test YE4.

The concrete cylinder test results show considerable scatter in test-day compressive strengths for Batch 1. Test results are given in Table 2.3. Using a least squares curve fit, regression curves for each concrete batch have been plotted in Figures 2.11 and 2.12. The first-order equation used in each case is inaccurate near the lower end of the curve since the initial strength-versus-age curve is highly nonlinear during the first 28 days.

Three of the cylinders broken on the day of the test were instrumented with strain gages. Parameters obtained from the experimental data are given below.

1. Average elastic modulus, $E_c = 73{,}500 \sqrt{f'_c}$ psi (where f'_c is the compressive strength of concrete)

2. Average Poisson's ratio, $\mu = 0.207$

3. Average strain at ultimate stress, $\varepsilon_o = 0.00204$

Using Hognestad's concrete model (Reference 5) with $\varepsilon_o = 0.00204$, the stress-strain relationship may be defined by the following equations:

1. For concrete strain, ε_c, less than ε_o

$$f_c = f'_c \left[\frac{2\varepsilon_c}{0.00204} - \left(\frac{\varepsilon_c}{0.00204} \right)^2 \right]$$

2. For concrete strains between ε_o and 0.0038

$$f_c = f'_c - \left(\frac{\varepsilon_c - 0.00204}{0.0038 - 0.00204} \right) \times 0.15 f'_c$$

The stress-strain curve defined by the above equations with $f'_c = 3{,}000$ psi is compared to actual stress-strain curves in Figure 2.13. Accuracy of the Hognestad model increases with strain up to ε_o. At ε_c of 0.0005, the ratio of theoretical to actual stress (σ_H/σ_T) varies from 1.17 to 2. At $\varepsilon_c = 0.001$, σ_H/σ_T varies from 1.17 to 1.33.

2.4.2 Reinforcing Steel

Design reinforcing yield stress was 60,000 psi. Reinforcing was deformed wire, heat-treated to an acceptable yield stress. Principal reinforcing was D3 wire (0.195-inch diameter) with an average yield stress of 63.3 ksi and an

average ultimate stress of 75.7 ksi. Transverse reinforcing and wall stirrups were D1 wire (0.113-inch diameter) with an average yield stress of 69.2 ksi. Results of tensile tests are given in Table 2.4.

2.4.3 Backfill

Sand backfill was a "flume sand" classified according to the Unified Soil Classification System as poorly graded sand (SP). Sand from the same source was found to have an angle of internal friction of 39.5 degrees (Reference 1). The sand was obtained from a commercial supplier in the Fort Polk, La., area. Sand was placed in 6-inch lifts and compacted with four passes of a 7-hp Dynapac Model CM-10 gasoline-powered vibrator. Vibrator output energy at 360 rpm is rated to produce 90 percent of optimum density in four passes on a 6-inch layer. Density was measured at two points for each lift in Test YE1 and for every second lift in Tests YE2 through YE4. Average dry and wet densities are given in Table 2.5.

Table 2.1. Instrumentation summary.

Gage	Location	Range	Manufacturer	Model
Airblast pressure	BP-1	1,000 psi	Kulite	HKS-375
	BP-2			
	BP-3			
	BP-4			
	BP-5			
	BP-6			
Soil stress	SE-1	4,000 psi		LQV-080-8UH
	SE-2	200 psi		LQV-080-8UHLR
	SE-3			
	SE-4			
	SE-5			
	SE-6			
	SE-7	4,000 psi		LQV-080-8UH
	SE-8			
	SE-9			
Accelerometer	A-1	2,000 g's	Endevco	2262
	A-2	400-2,000 g's		
	AFF-1	2,000 g's		
Interface pressure	IF-1	500 psi		VM-750
	IF-2			
	IF-3			
	IF-4			
	IF-5	200 psi		
Strain	EO-1	10,000 uin/in	Micro-Measurements	EA-06-250BF-350-W
	EI-1			
	EO-2			
	EI-2			
	EO-3			
	EI-3			
	EO-4			
	EI-4			
	E-5			
	E-6			
	E-7			
	E-8			
	EO-1A			
	EI-1A			
	EO-2A			
	EI-2A			
	EO-3A			
	EI-3A			
	EO-4A			
	EI-4A			
	E-5A			
	E-6A			
	E-7A			
	E-8A			
Deflection	D-1	10 inch	Celesco	PT-101-10-A-7559
	D-2			

Table 2.2. Weapon simulation parameters.

Test No.	Cavity Size ft × ft × ft	Depth of Overburden ft	Charge Density lb/ft^3
YE1	16 × 16 × 3	4	0.016
YE2	12 × 12 × 2	2	0.040
YE3	16 × 16 × 3	4	0.016
YE4	12 × 12 × 1	2	0.036

Table 2.3. Concrete compressive strengths

Test	Element No.	Concrete Batch	7-Day Compressive Strength psi	28-Day Compressive Strength psi	Day of Test: Compressive Strength psi	Day of Test: Compressive Strength Based on Regression Analysis psi	Day of Test: Age When Tested days
YE1	1	1	1,910	2,979	3,110		43
					3,050		43
					3,150		43
					3,080	3,093	43
YE2	2	1			3,030		49
					3,010		49
					3,130		49
					3,660		49
					3,310	3,261	49
YE4	3	2		2,870	3,130		68
				2,800	3,410		68
				2,600	3,290	3,277	68
				2,700			
YE3	5	2			2,910		48
					2,840		48
					2,980		48
					3,170	2,975	48

Table 2.4. Results of tensile tests on reinforcing steel.

Deformed Wire Size	Use	Yield Stress ksi	Ultimate Stress ksi	Rupture Stress ksi
D-3	Principal reinforcing	68.4	79.2	--
		63.3	76.8	76.8
		68.3	81	52.5
		65	77	--
		64	73.8	73.8
		68.4	79.8	52.5
		64.7	77.5	77.5
		60	74	74
		55.8	66.7	66.7
		53.3	64	64
		72	85	76.7
		62	76.3	76.3
		65	78.3	78.3
		56.7	70.2	--
D-1	Transverse reinforcing	67	73.5	--
		65	73.5	--
		67.5	74	--
D-1	Stirrups	65	75	75
		70	75.5	52.5
		75	80.5	50
		76	82	40
		65	--	--

Table 2.5. Average backfill density readings.

Test	Depth Below Grade ft	Average Wet Density lb/ft^3	Average Dry Density lb/ft^3	Average Moisture Content lb/ft^3	Percent Moisture
YE1	4.1	107.9	102.7	5.3	5.1
	3.6	107.5	102.4	5.2	5.1
	3.1	108.7	103.3	5.5	5.3
	2.6	105.6	110.6	5.0	4.5
	2.1	108.9	150.3	4.6	3.4
	1.6	110.8	106.4	4.5	4.2
	1.0	107.8	103.8	4.1	3.9
	0.5	108.6	103.7	5.0	4.8
	0.0	106.4	101.7	4.8	4.7
	Average	108.0	104.4	4.9	4.6
YE2	4.1	109.7	102.4	6.9	6.8
	3.1	109.1	101.9	7.3	6.6
	2.1	110.8	102.7	8.0	7.8
	1.0	109.8	103.9	5.9	5.6
	0.0	107.3	103.0	4.3	4.1
	Average	109.3	102.8	6.5	6.2
YE3	4.1	109.3	104.3	5.0	4.9
	3.1	110.0	103.5	6.6	6.4
	2.1	110.8	104.8	6.1	5.8
	1.0	109.4	103.7	5.8	5.6
	0.0	109.5	104.8	4.7	4.5
	Average	109.8	104.2	5.6	5.4
YE4	4.1	110.7	105.6	5.2	4.9
	3.1	110.5	103.3	7.2	6.9
	2.1	111.8	102.8	9.1	8.8
	1.0	110.8	102.5	8.4	8.2
	0.0	108.6	102.4	6.2	6.1
	Average	110.5	103.3	7.2	7.0

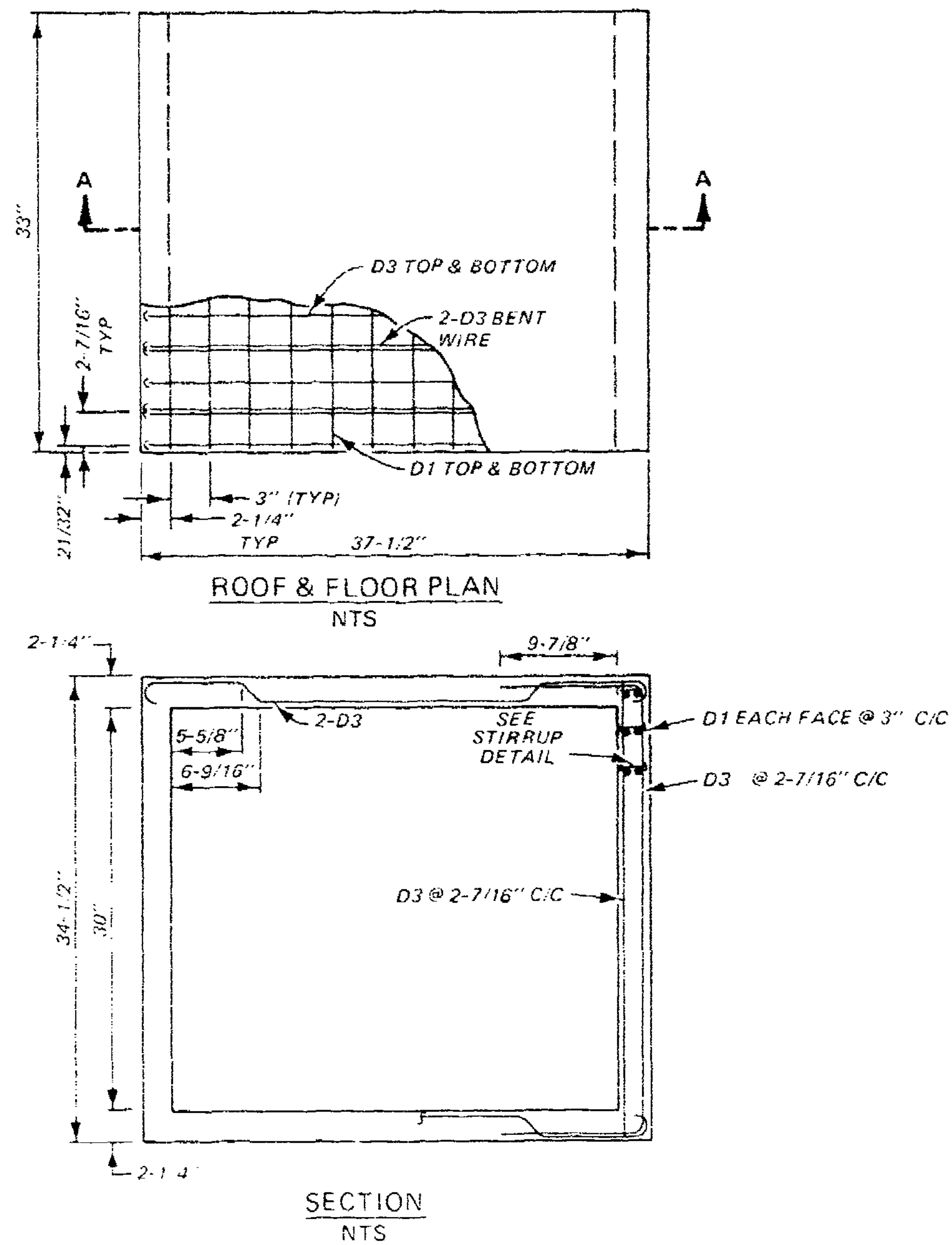


Figure 2.1. Typical box plan and section.

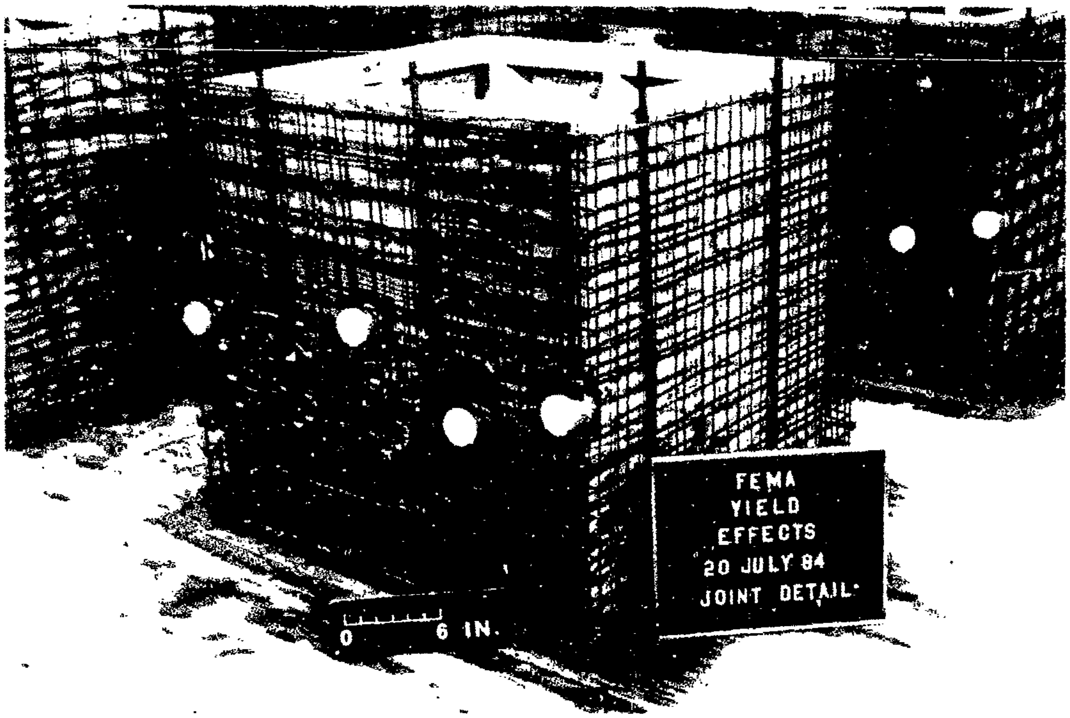


Figure 2.2. Yield effects tests, typical joint detail.

Figure 2.3. Yield effects tests, construction details.

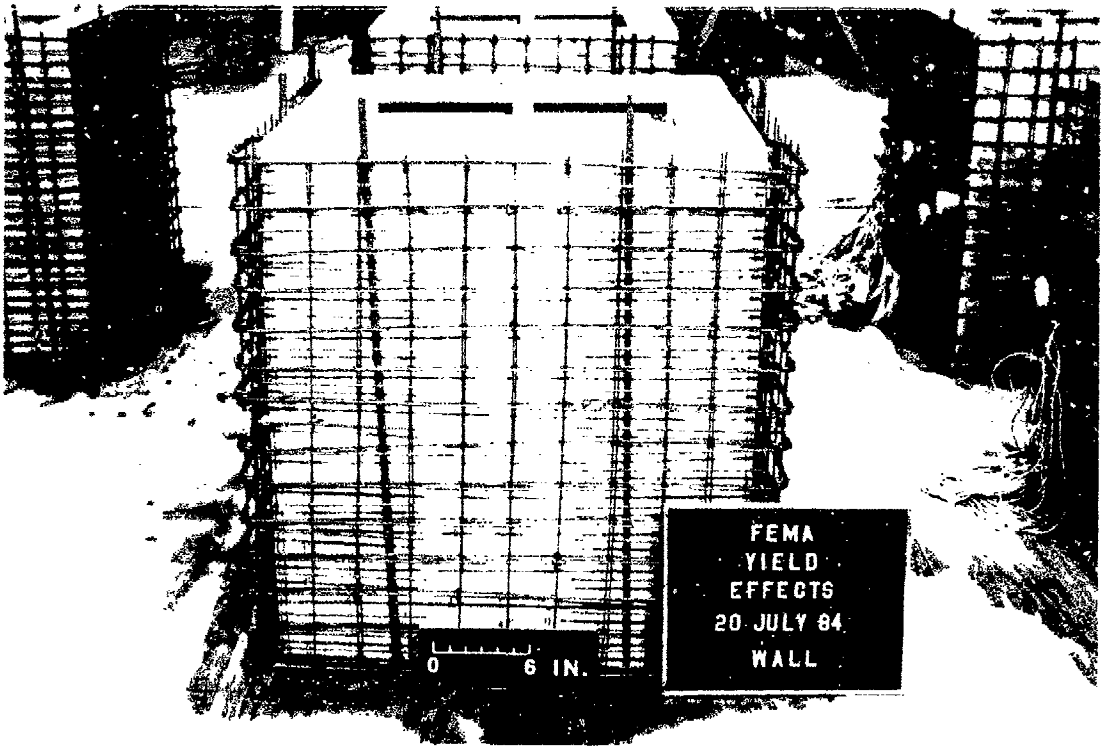


Figure 2.4. Yield effects tests, typical wall reinforcing.

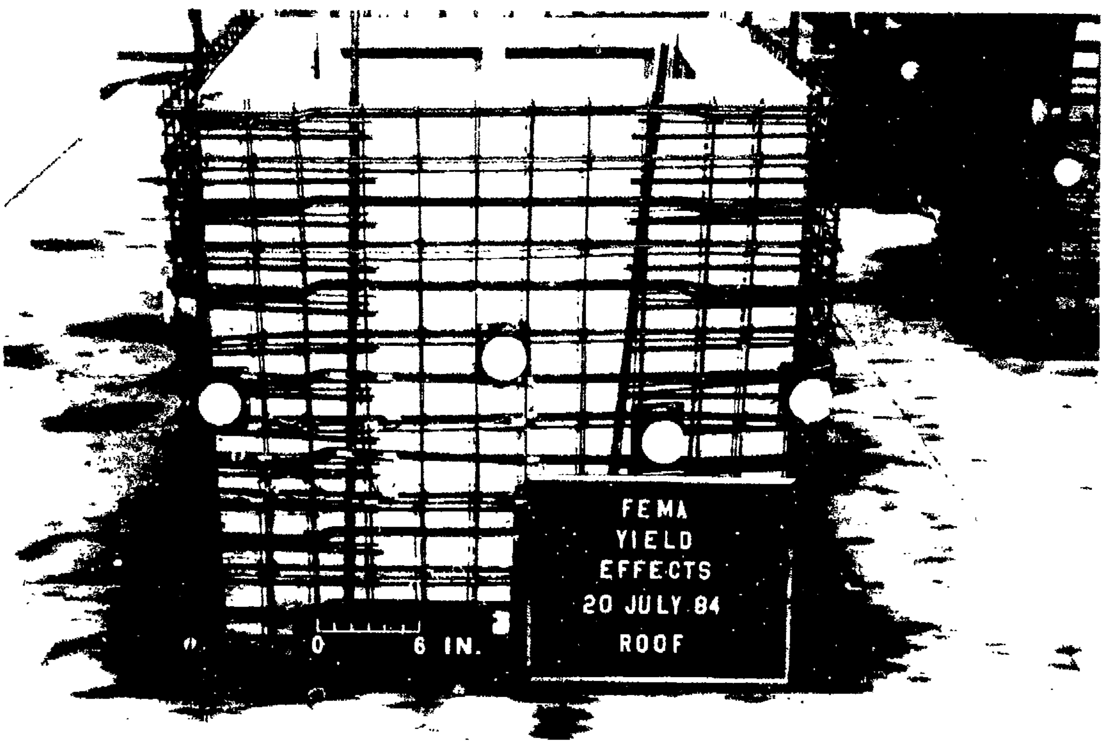


Figure 2.5. Yield effects tests, typical roof reinforcing.

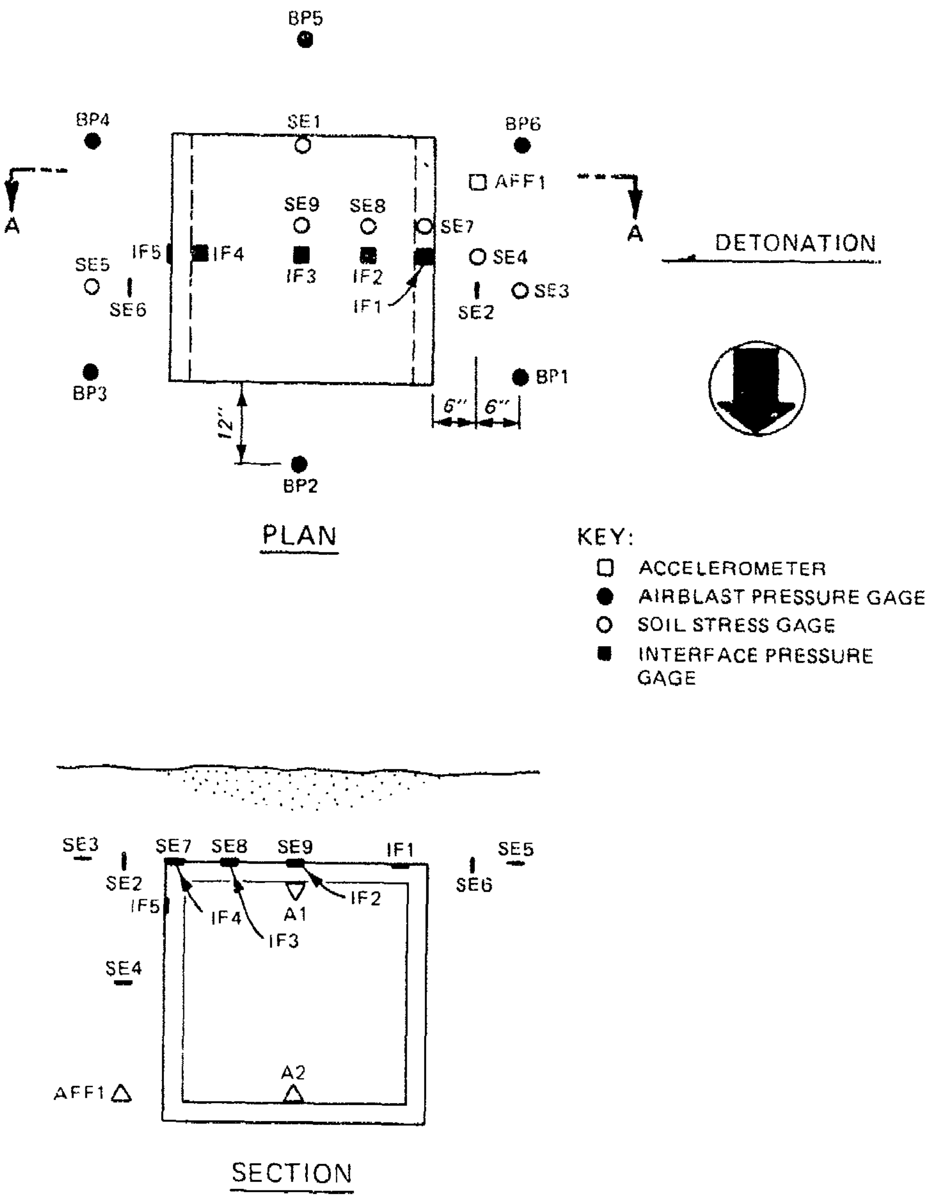


Figure 2.6. Instrumentation layout, Test YE1.

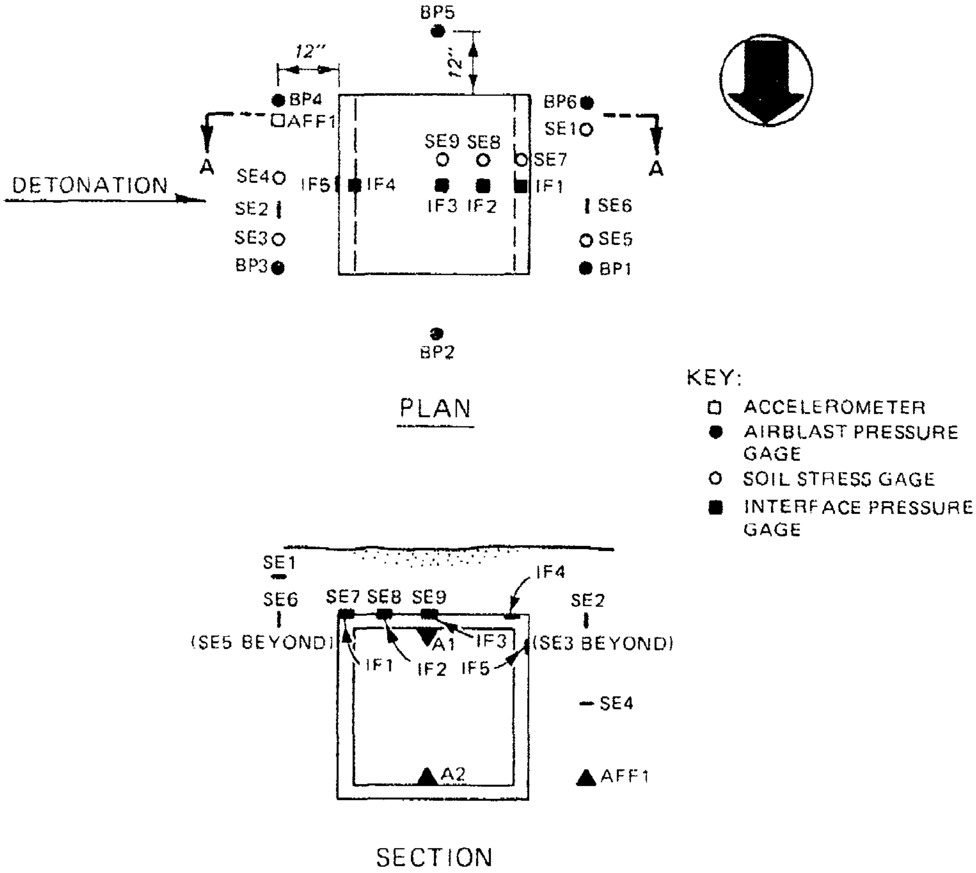


Figure 2.7. Instrumentation layout, Tests YE2 through YE4.

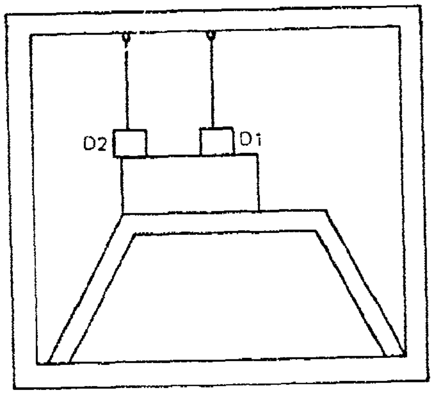


Figure 2.8. Typical deflection gage locations.

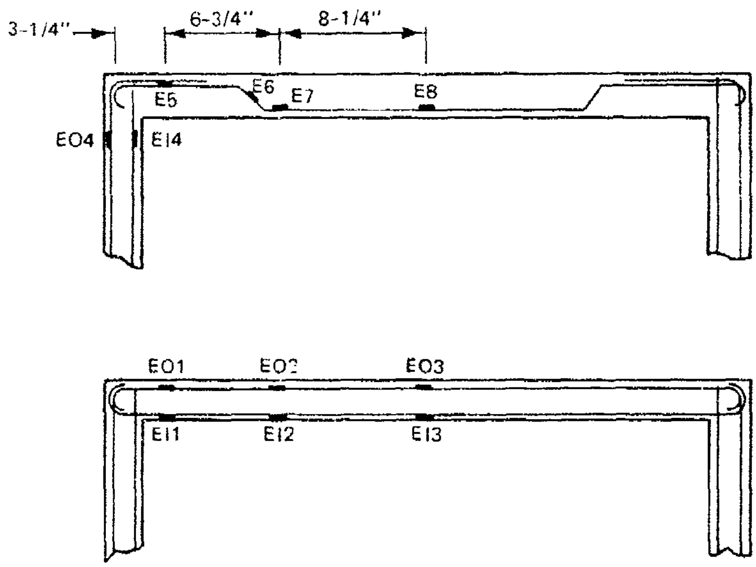


Figure 2.9. Typical strain gage locations.

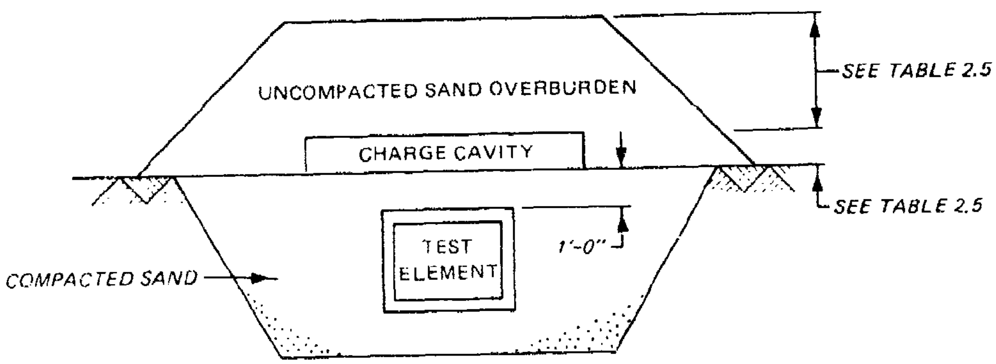


Figure 2.10. Typical test bed configuration.

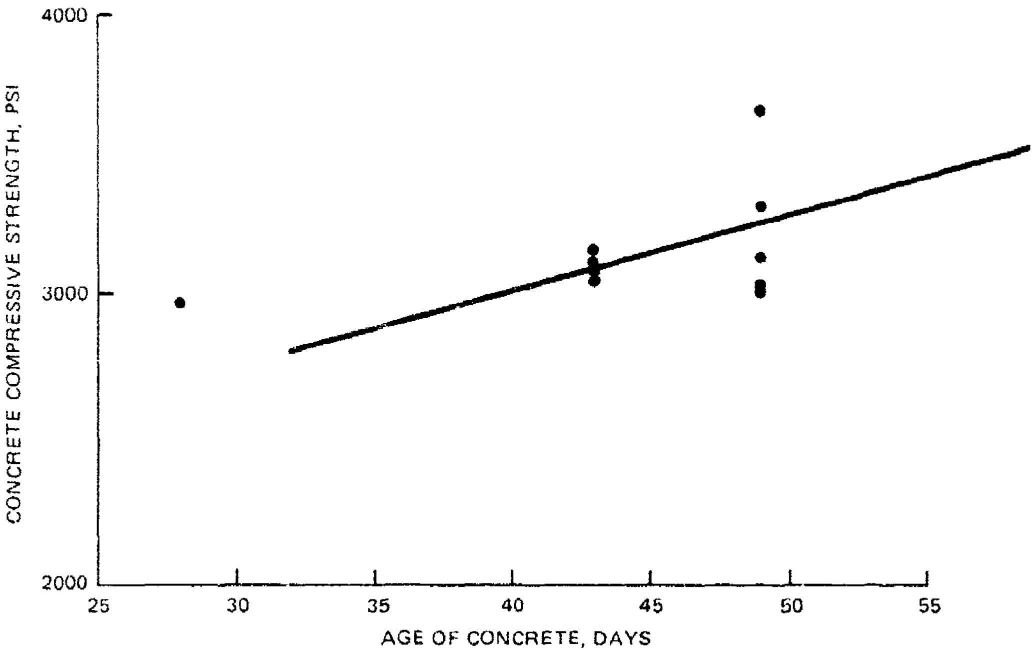


Figure 2.11. Concrete compressive strength versus age, Batch 1.

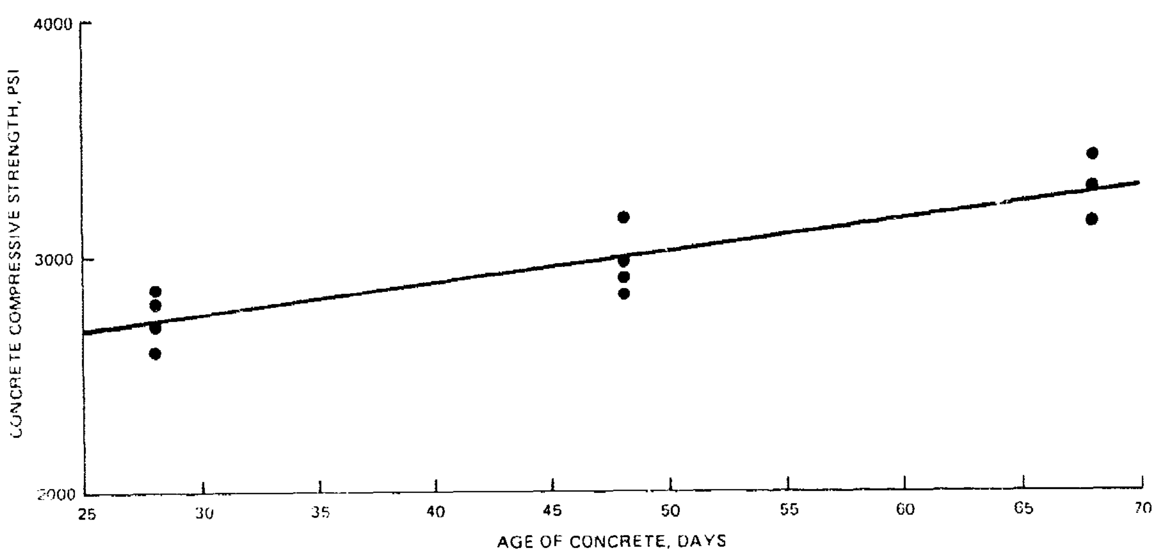


Figure 2.12. Concrete compressive strength versus age, Batch 2.

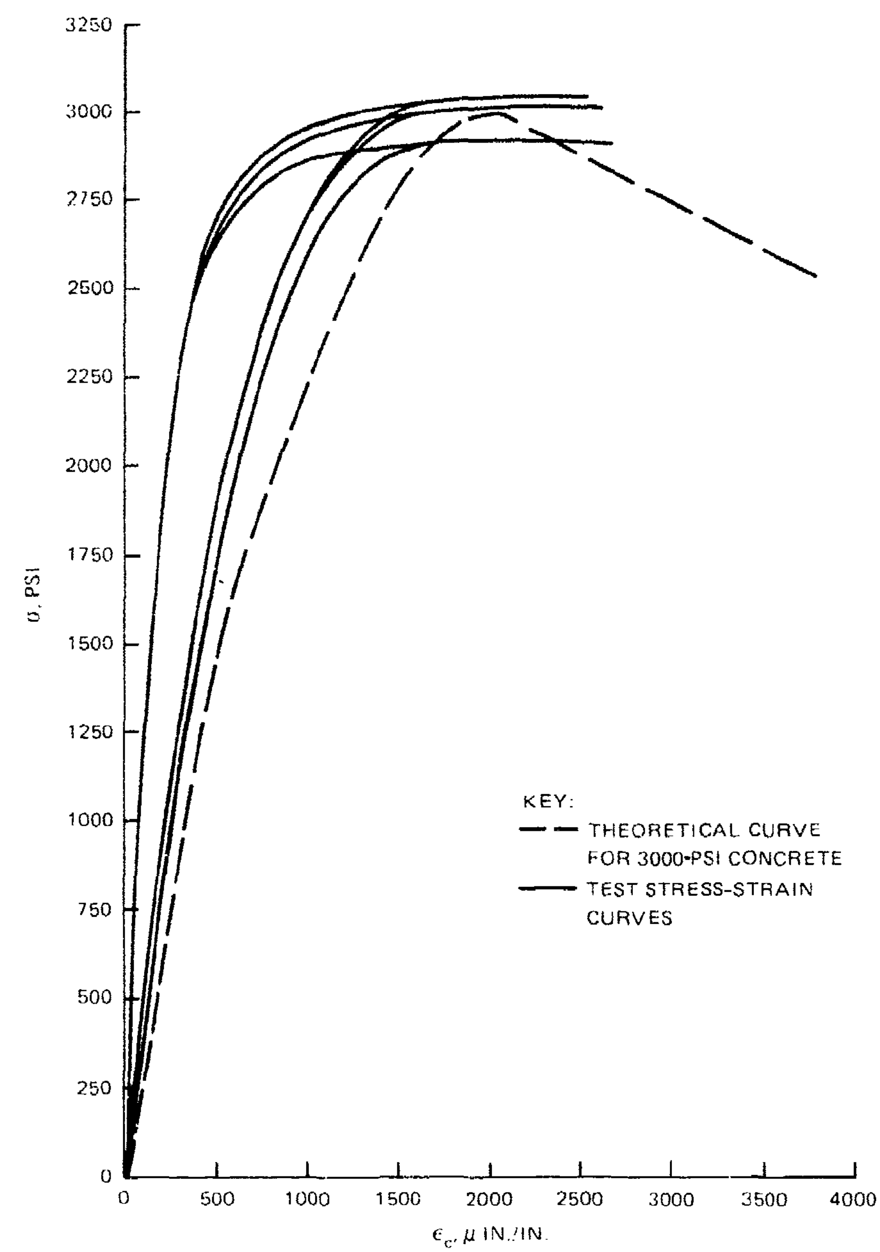


Figure 2.13. Theoretical and test concrete stress-strain curves.

CHAPTER 3

TEST RESULTS

3.1 DAMAGE

The structural models were uncovered and examined immediately after testing. In every case the roofs cracked at supports and midspan on the top surface, indicating a three-hinge failure mechanism rather than the tensile membrane behavior observed under more impulsive loadings (Reference 6).

Maximum permanent roof midspan deflection for Test 1, the baseline test, was 13/32 inch. Center cracks and cracks over roof supports ranged in depth from 1-1/2 inches to the thickness of the roof. The inside surface of the floor also showed some midspan cracks, and wall cracks occurred near the tops of both walls.

Test 2 (low yield, high overpressure) resulted in a permanent deflection of approximately 4-1/2 inches at midspan, exposing reinforcing near the roof midspan and supports. Bottom steel was broken at midspan. Cracks over supports and in the walls at the supports were 2 to 2-1/4 inches deep. Several cracks occurred in the top side of the floor approximately at midspan.

The box roof failed in Test 3 (baseline weapon, no wall stirrups) with a permanent midspan deflection of 9-1/2 inches. All roof reinforcing at midspan and at supports was exposed, and bottom midspan bars were broken. Severe cracks occurred in both walls slightly below midspan, with the west wall buckling at that point. Cracks also occurred at the floor-wall connections.

Permanent roof deflection in Test 4 (low yield, high overpressure) was only 1/4 inch. Hairline cracks were observed at supports and midspan on the top of the roof and across the surface of the bottom of the roof. There was no visible damage to the floor or walls except for a hairline crack at the top of the exterior east wall.

Pre- and posttest surveys indicate that the structures were skewed after the detonation, with the side closest the detonation moving upward from 3/4 inch to 1-1/3 inches and the opposite side moving downward from 1/8 inch to 2 inches. The average top-of-box elevation was higher after each test, with the greatest upward movement in Test YE4. Survey results are given in Table 3.1.

Posttest photographs are shown in Figures 3.1 through 3.14.

3.2 DATA

A summary of data from the four tests is given in Tables 3.2 through 3.5. Data plots are included in Appendix A.

Data recovery for the tests was good, although several channels of data were not recovered in Test YE2. When possible, data are given for the first 50 ms of the test. Some strain gage data were for shorter time spans.

Table 3.1. Relative pre- and posttest elevations.

Station	Test YE1 Pretest Elevations ft	Test YE1 Posttest Elevations ft	Test YE2 Pretest Elevations ft	Test YE2 Posttest Elevations ft	Test YE3 Pretest Elevations ft	Test YE3 Posttest Elevations ft	Test YE4 Pretest Elevations ft	Test YE4 Posttest Elevations ft
TBM1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1	-1.67	-1.61	-1.58	-1.49	-1.54	-1.48	-1.59	-1.48
2	-1.68	-1.67	-1.58	-1.80	-1.57	-2.39	-1.57	-1.49
3	-1.68	-1.66	-1.57	-1.72	-1.57	-1.54	-1.57	-1.49
4	-1.67	-1.68	-1.59	-1.52	-1.56	-1.60	-1.57	-1.52
5	-1.69	-1.71	-1.59	-1.58	-1.56	-1.59	-1.58	-1.56
6	-1.69	-1.72	-1.59	-1.88	-1.56	-2.41	-1.58	-1.58
7	-1.68	-1.68	-1.58	-1.57	-1.57	-1.63	-1.59	-1.55
8	-1.69	-1.65	-1.59	-1.52	-1.57	--	-1.59	-1.52
9	-1.69	-1.68	-1.59	-1.84	-1.57	--	-1.58	-1.53

Table 3.2. Data summary, Test YE1.

Gage	Location	Time Span ms	Comments
Airblast pressure	BP-1	50	
	BP-2		
	BP-3		
	BP-4		
	BP-5		
	BP-6		
Soil stress	SE-1	50	
	SE-2		
	SE-3		
	SE-4		
	SE-5		
	SE-6		Not recovered
	SE-7		
	SE-8		
	SE-9		
Acceleration	AFF-1	50	
	A-1		
	A-2		
Interface pressure	IF-[illegible]	50	Not recovered
	IF-2		
	IF-3		
	IF-4		
	IF-5		
Deflection	D-1	50	
	D-2		Not recovered

Gage	Location	Time Span ms	Comments
Strain	EO-1		
	EO-1A		
	EI-1		Not used
	EI-1A		
	EO-2		
	EO-2A		
	EI-2		
	EI-2A		
	EO-3		Not used
	EO-3A		
	EI-3		
	EI-3A		
	EO-4		
	EO-4A		
	EI-4	50	
	EI-4A		
	E-5		
	E-5A		
	E-6		
	E-6A		
	E-7		
	E-7A		
	E-8		
	E-8A		

Table 3.3. Data summary, Test YE2.

Gage	Location	Time Span ms	Comments
Airblast pressure	BP-1	50	
	BP-2		
	BP-3		
	BP-4		Not recovered
	BP-5		
	BP-6		
Soil stress	SE-1	2	Clipped at 2 ms
	SE-2		
	SE-3		
	SE-4		
	SE-5		Not recovered
	SE-6		
	SE-7		
	SE-8		Not recovered
	SE-9		
Acceleration	AFF-1	50	
	A-1		
	A-2		
Interface pressure	IF-1	50	
	IF-2		
	IF-3		
	IF-4		
	IF-5		
Deflection	D-1	50	
	D-2		

Gage	Location	Time Span ms	Comments
Strain	EO-1	5	Clipped at 5 ms
	EO-1A	50	
	EI-1		
	EI-1A		
	EO-2		
	EO-2A		
	EI-2		
	EI-2A		
	EO-3	35	Clipped at 35 ms
	EO-3A	16	Clipped at 16 ms
	EI-3	28	Clipped at 28 ms
	EI-3A	6	Clipped at 6 ms
	EO-4		Not recovered
	EO-4A		Not recovered
	EI-4	50	
	EI-4A		
	E-5		
	E-5A		Not recovered
	E-6		
	E-6A		Not used
	E-7		Not used
	E-7A		
	E-8	12.5	Clipped at 12.5 ms
	E-8A		Not recovered

Table 3.4. Data summary, Test YE3.

Gage	Location	Time Span ms	Comments
Airblast pressure	BP-1	50	
	BP-2		
	BP-3		
	BP-4		
	BP-5		
	BP-6		
Soil stress	SE-1	50	
	SE-2		
	SE-3		
	SE-4		
	SE-5		
	SE-6		
	SE-7		
	SE-8		
	SE-9		
Acceleration	AFF-1	50	
	A-1		
	A-2		
Interface pressure	IF-1	50	
	IF-2		
	IF-3		
	IF-4		
	IF-5		
Deflection	D-1	50	Clipped at 26 ms
	D-2		Clipped at 23 ms

Gage	Location	Time Span ms	Comments
Strain	EO-1	50	
	EO-1A		
	EI-1		Not recovered
	EI-1A		
	EO-2		
	EO-2A		
	EI-2		
	EI-2A		
	EO-3		Clipped at 31 ms
	EO-3A	16	Clipped at 27 ms
	EI-3	28	Clipped at 19 ms
	EI-3A	6	Clipped at 7 ms
	EO-4		
	EO-4A		
	EI-4	50	
	EI-4A		
	E-5		
	E-5A		
	E-6		
	E-6A		
	E-7		
	E-7A		Clipped at 42.5 ms
	E-8		Clipped at 7 ms
	E-8A		Clipped at 9 ms

Table 3.5. Data summary, Test YE4.

Gage	Location	Time Span ms	Comments
Airblast pressure	BP-1	50	
	BP-2		
	BP-3		
	BP-4		
	BP-5		
	BP-6		
Soil stress	SE-1	50	
	SE-2		
	SE-3		
	SE-4		
	SE-5		
	SE-6		
	SE-7		
	SE-8		
	SE-9		
Acceleration	AFF-1	50	
	A-1		
	A-2		
Interface pressure	IF-1	50	
	IF-2		
	IF-3		
	IF-4		
	IF-5		
Deflection	D-1	50	
	D-2		Not recovered
Strain	EO-1	50	
	EO-1A		
	EI-1		
	EI-1A		
	EO-2		
	EO-2A		Not used
	EI-2		
	EI-2A		
	EO-3		
	EO-3A		
	EI-3		
	EI-3A		
	EO-4		
	EO-4A		
	EI-4	50	
	EI-4A		
	E-5		
	E-5A		
	E-6		Not used
	E-6A		
	E-7		
	E-7A		
	E-8		Clipped at 8 ms
	E-8A		

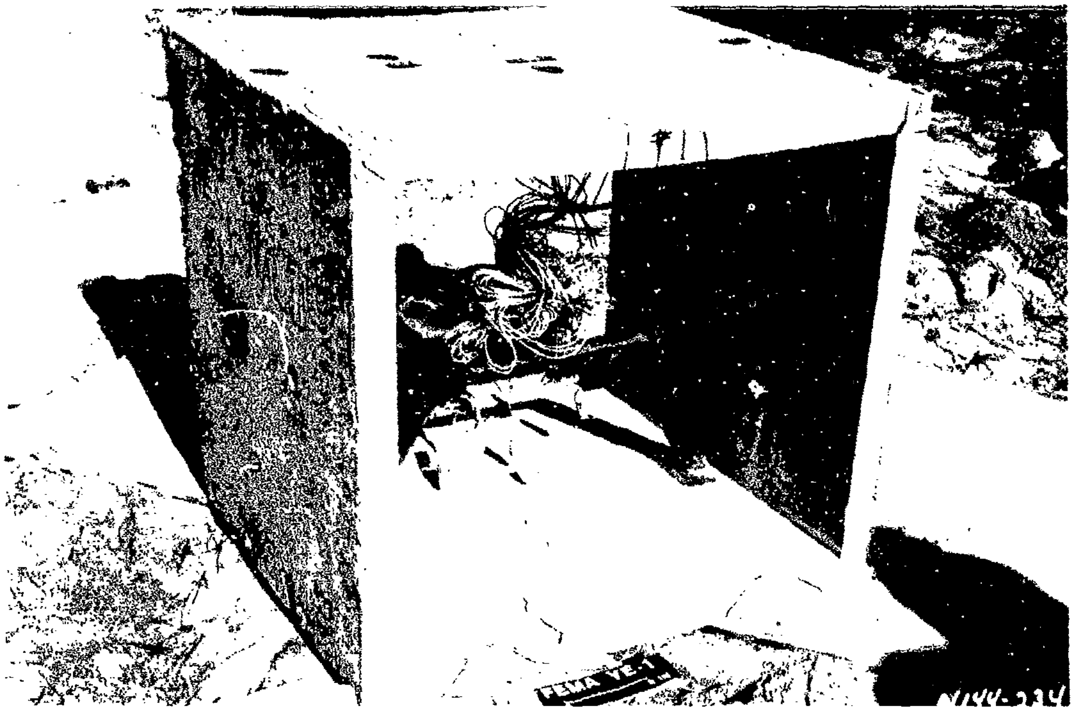


Figure 3.1. Posttest view, Test YE1.

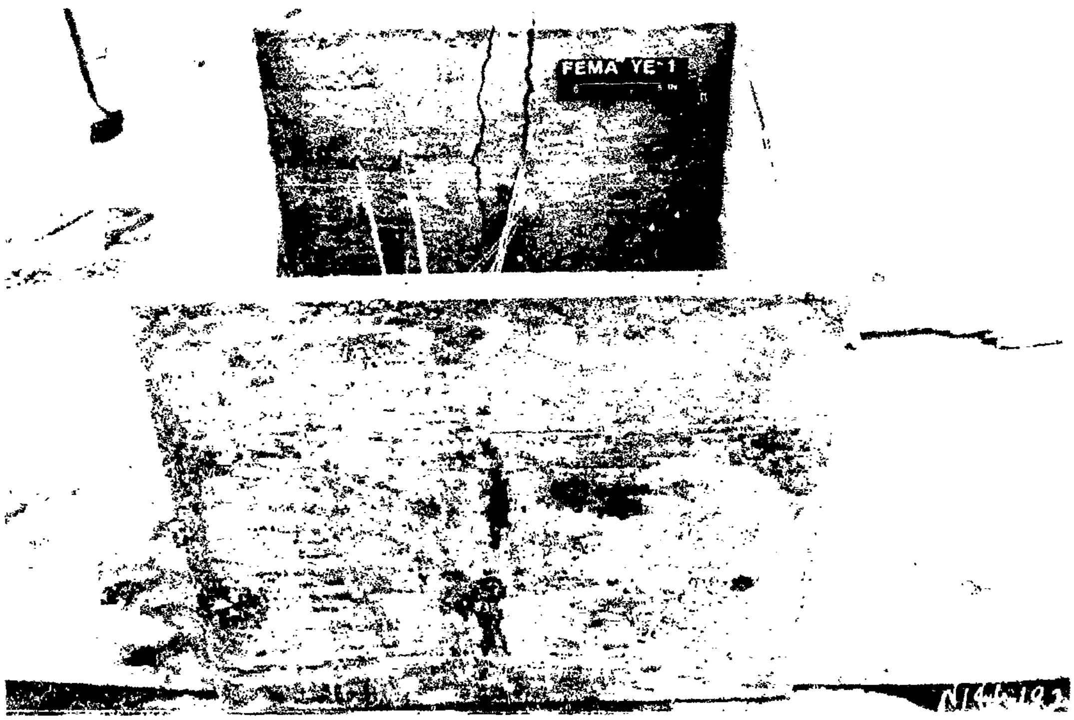


Figure 3.2. Posttest view inside roof, Test YE1.

Figure 3.3. Posttest view, roof, Test YE1.

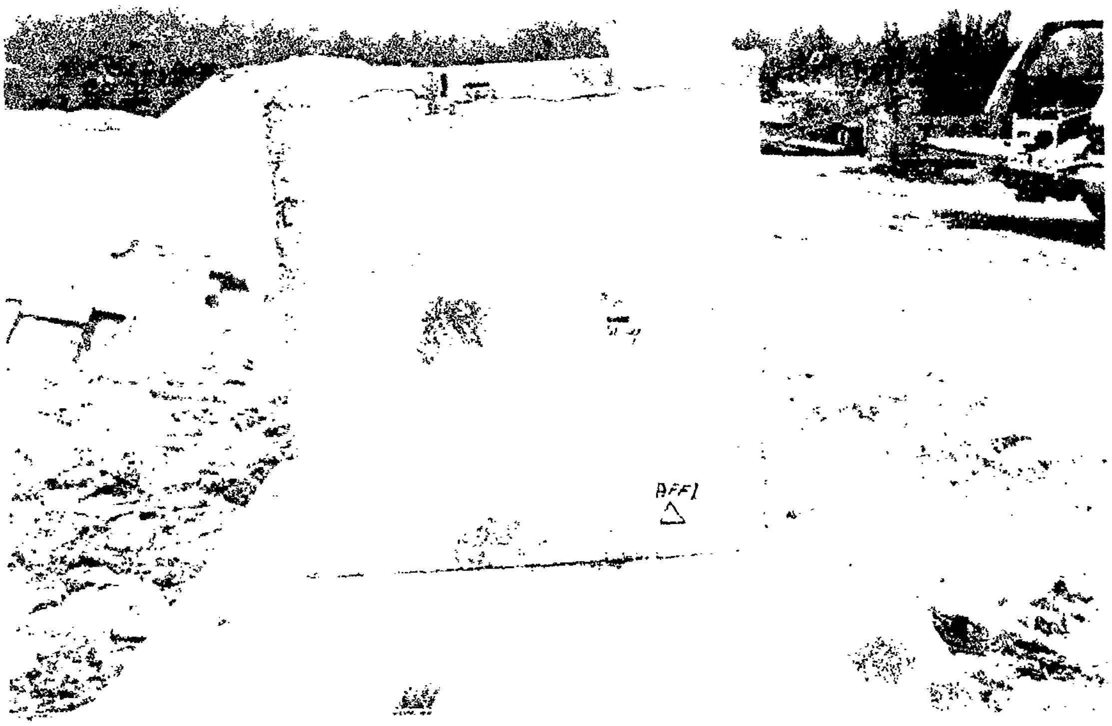


Figure 3.4. Wall cracks, Test YE1.

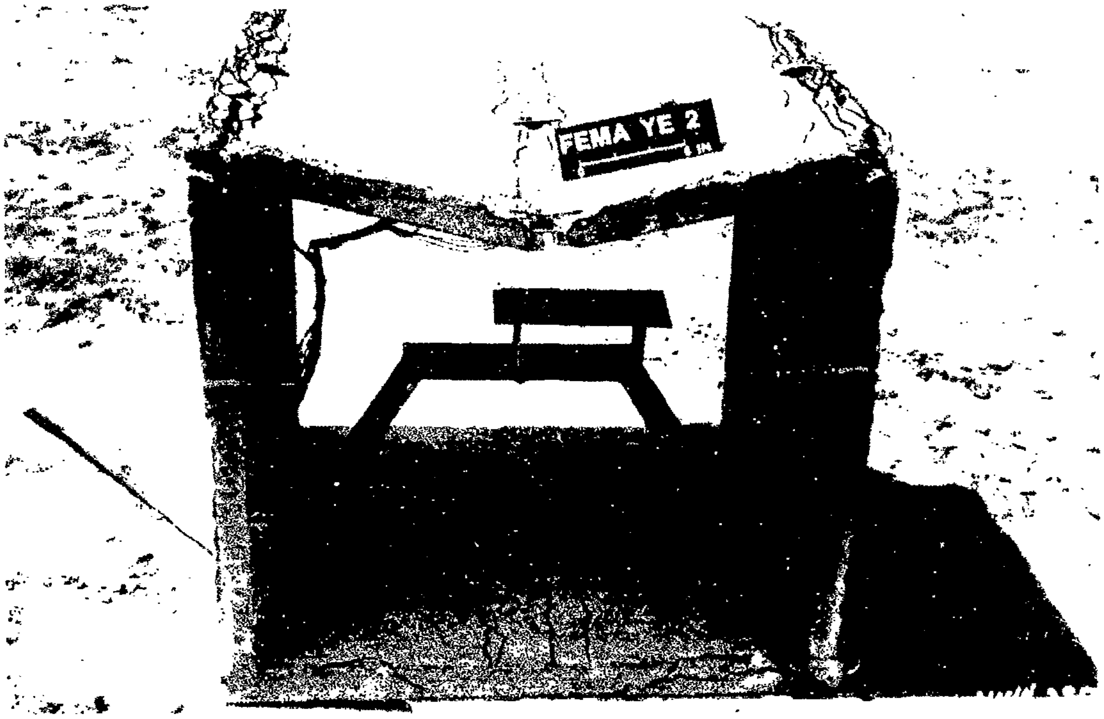


Figure 3.5. Posttest view, Test YE2.

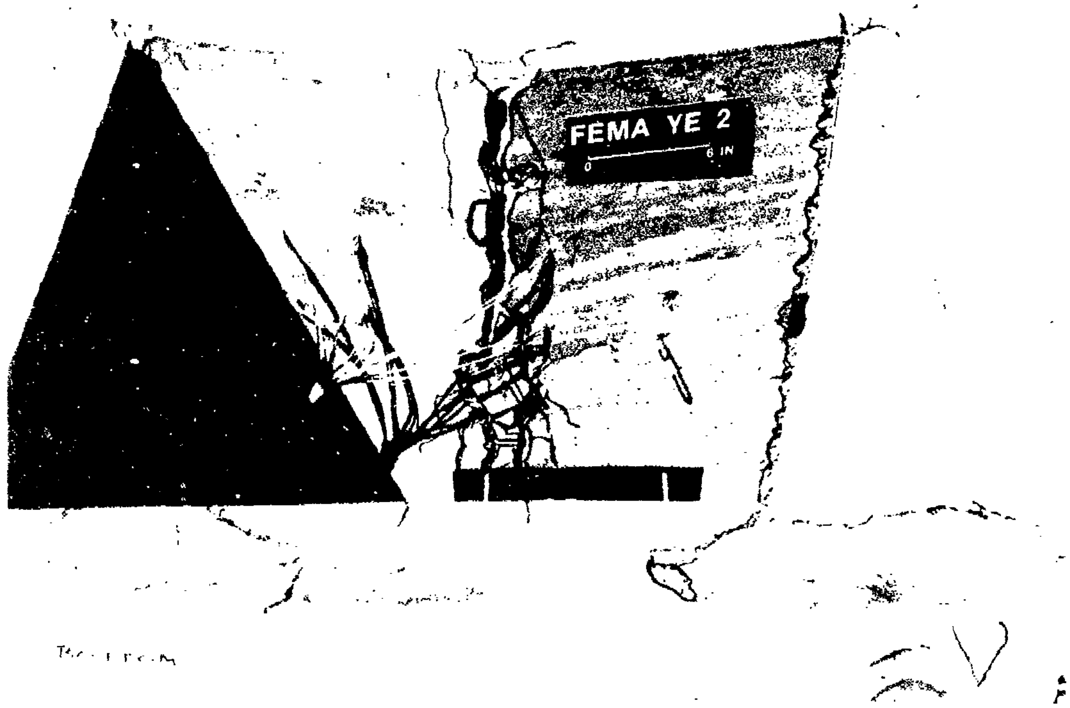


Figure 3.6. Posttest view inside roof, Test YE2.

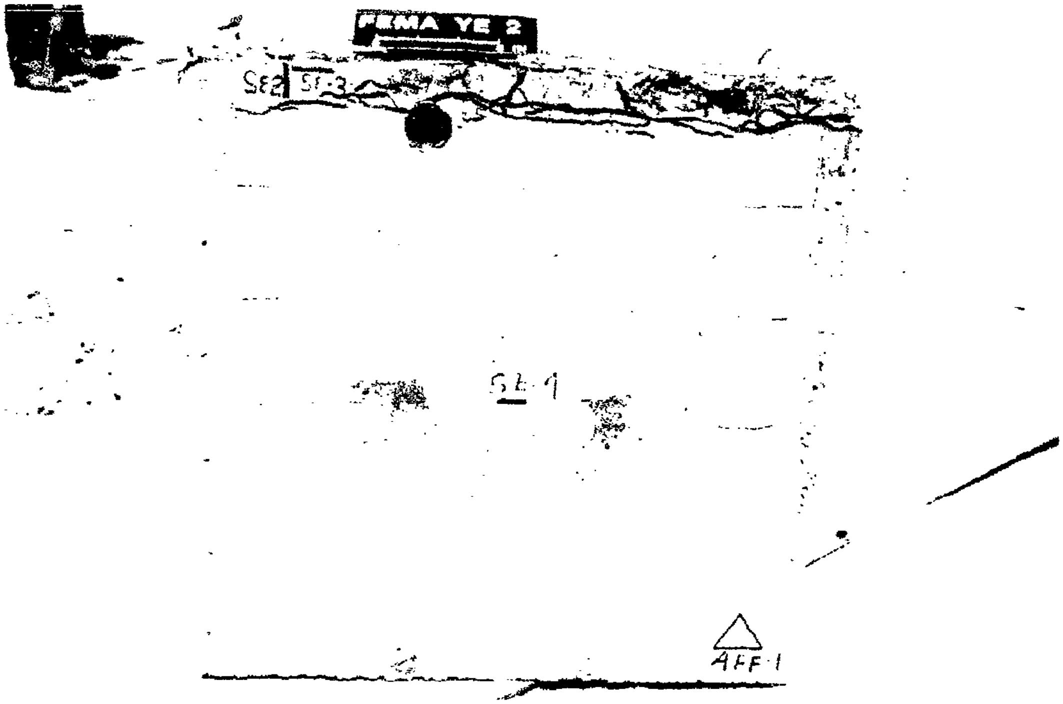


Figure 3.7. Wall cracks, Test YE2.

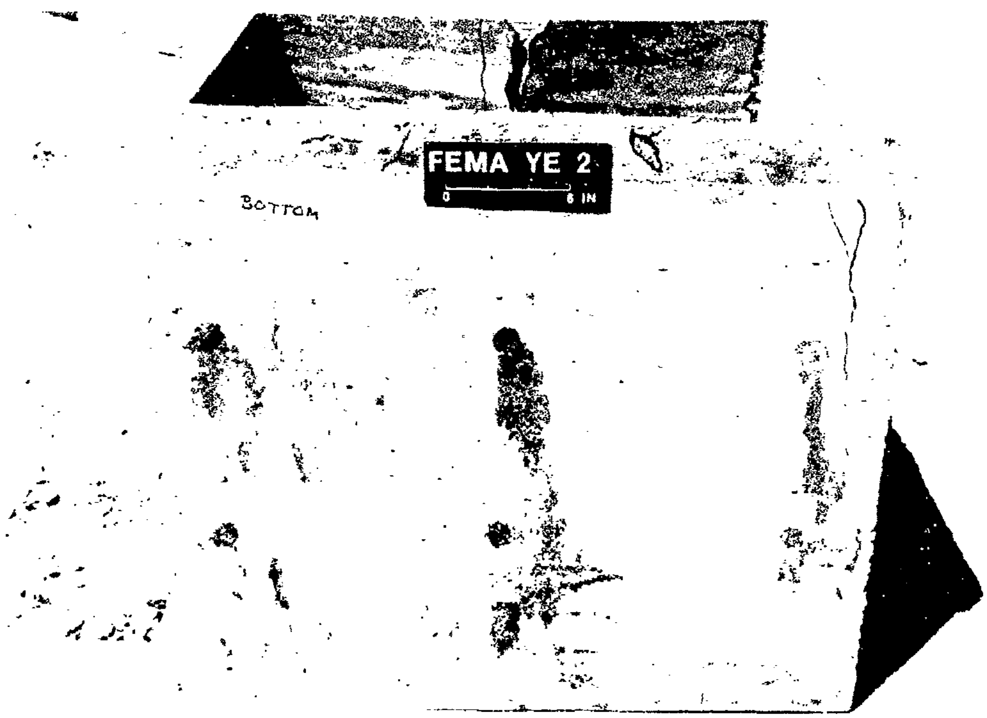


Figure 3.8. Bottom of box, Test YE2.

Figure 3.9. Posttest view, Test YE3.

Figure 3.10. East wall damage, Test YE3.

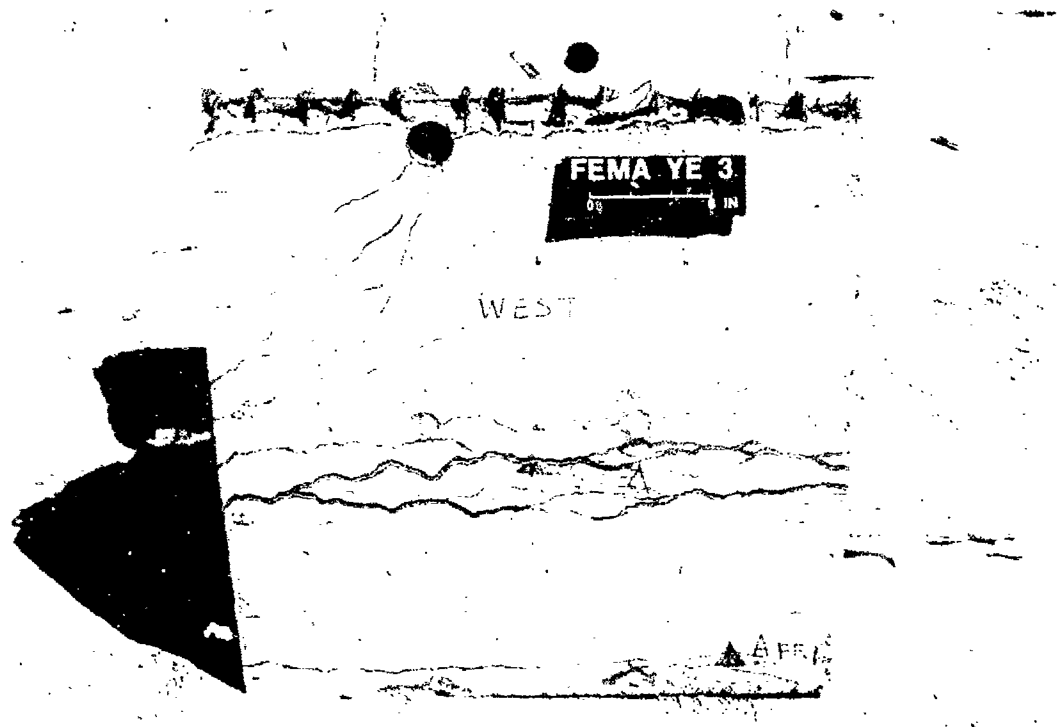


Figure 3.11. West wall damage, Test YE3.

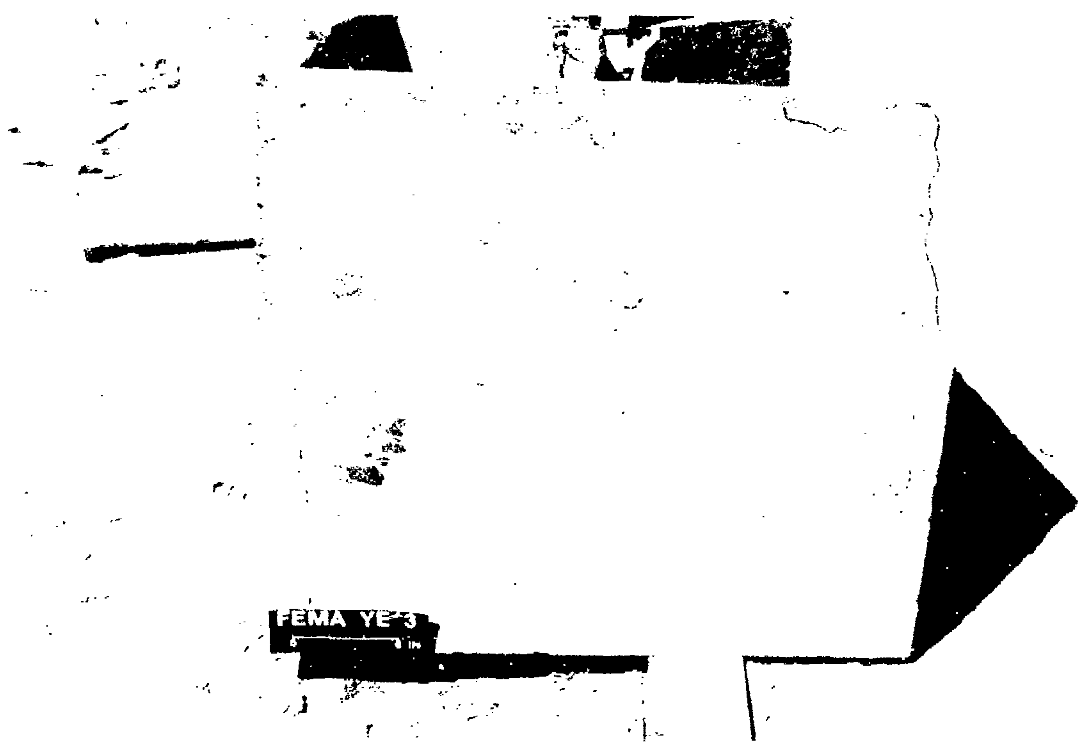


Figure 3.12. Bottom of box, Test YE3.

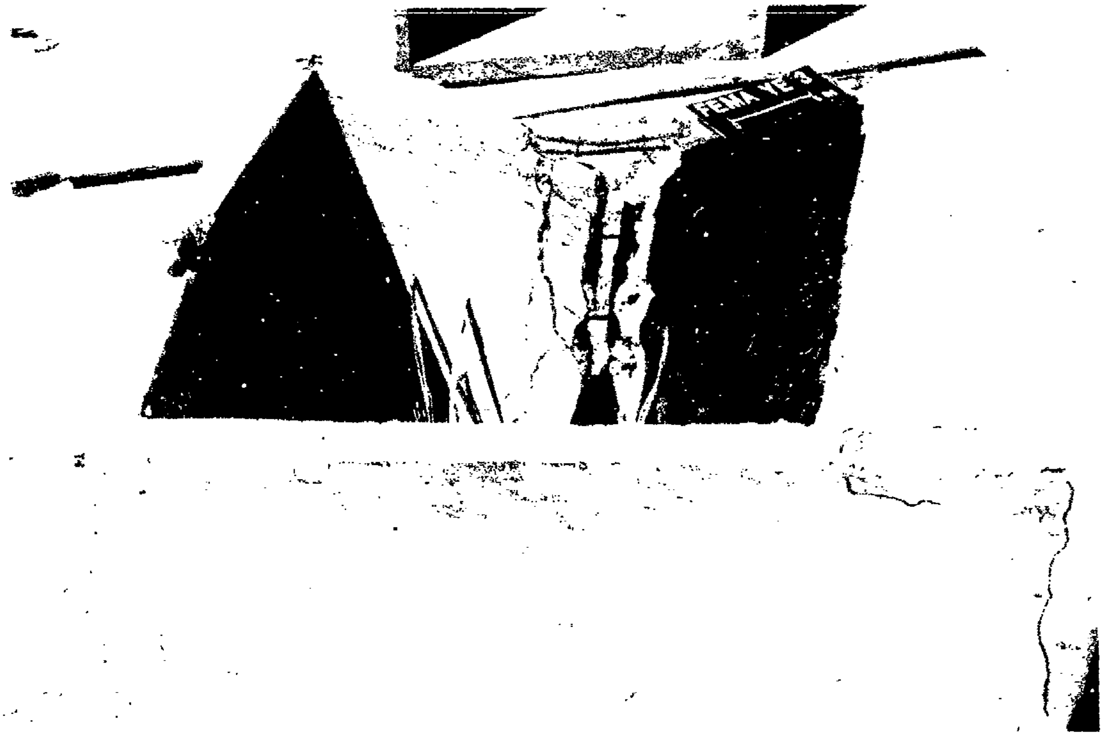


Figure 3.13. Inside roof, Test YE3.

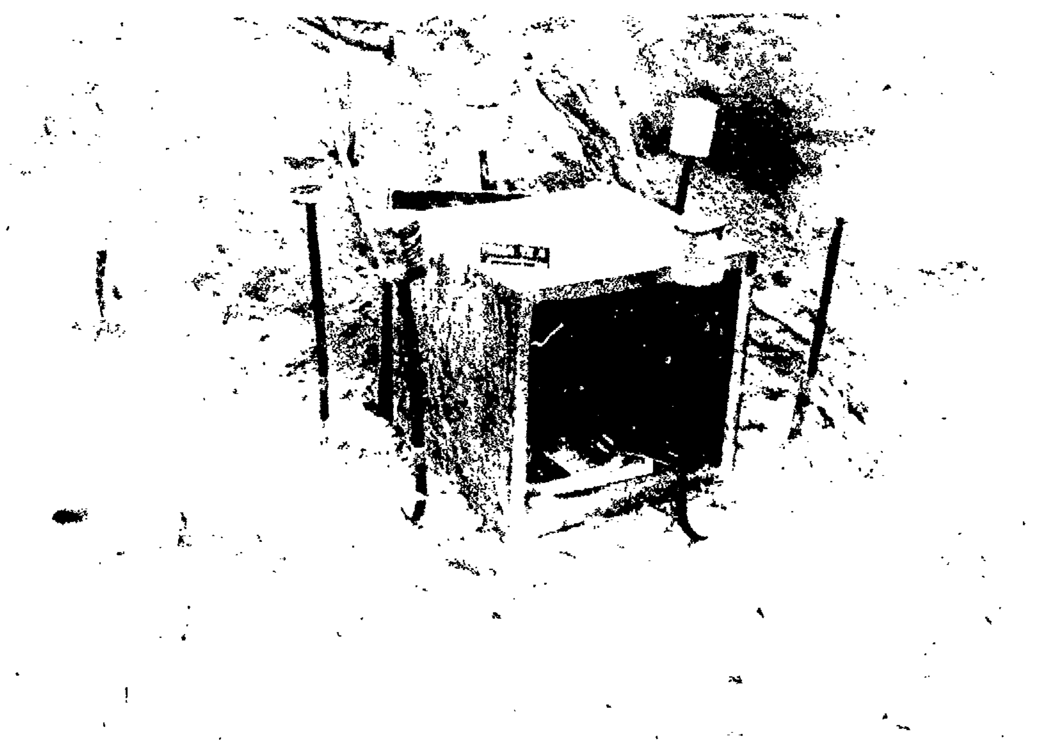


Figure 3.14. Posttest view, Test YE4.

CHAPTER 4

ANALYSIS

4.1 NUCLEAR WEAPON SIMULATIONS

Data from airblast pressure gages were fitted to the impulse-time records defined by Brode (Reference 7) and modified to include the work of Speicher and Brode (Reference 8) using a least-squares curve fit developed by Mlakar and Walker (Reference 9). Simulated yield and overpressure for each gage as well as the average for each test for 20 ms of data are given in Table 4.1. Best-fit nuclear weapon pressures and impulses have been superimposed over actual pressure and impulse histories and are included in Appendix B.

4.2 STRAIN GAGE DATA

Bent roof bars yielded at supports and at quarter- and midspan in Test YE1, the baseline test. Straight tensile bars yielded at supports and at midspan. First yield in both bent and straight bars occurred at supports, indicating that the first hinge was formed there.

In Test YE2 (low yield, high overpressure) straight tensile bars yielded at the supports and midspan, with top reinforcing at midspan yielding in tension at a later time. First yield occurred at midspan, and bent bars yielded only at midspan.

In Test YE3 (baseline weapon, no wall stirrups) straight tensile bars yielded at supports and midspan at approximately the same time, with top reinforcing yielding at midspan at a much later time. Bent bars yielded at supports, quarter-span, and midspan.

In Test YE4 (low yield, high overpressure) straight tensile bars yielded at supports and midspan at approximately the same time. Bent bars yielded at supports, quarter-span, and midspan, with first yield apparently at midspan.

From an observation of wall reinforcing strain gage data (EO-4 and EI-4), an abrupt increase in compression in the section occurred at about 8-1/2 ms in both Test YE3 and Test YE1. In Test YE1 after about 12 ms concrete strains (calculated from reinforcing strain gage data) exceeded 0.0038, in Test YE3 but very little increase occurred after that time. Concrete strains in Test YE3 almost immediately exceeded 0.0038 and continued to increase until crushing occurred. This indicates that wall hinges occurred at an early time,

preceding the formation of the midspan roof hinge.

Since wall stirrups were omitted in the element in Test YE3, the concrete was not as well confined as in Test YE1, and less lateral support was provided for compressive reinforcing. Apparently the wall without stirrups lacked the ductility to deflect and support large compressive loads without buckling.

4.3 COMPARISON OF ANALYSIS AND TEST RESULTS

The VSBS program (modified for compressive membrane effects) was used to analyze the four structures tested, using average weapon simulations to describe loading. Results of the single-degree-of-freedom analysis are given in Table 4.2.

The VSBS program uses a parabolic load distribution as shown in Figure 4.1 with a soil arching factor based on an equation developed by McNulty (Reference 10) and modified by Kiger (Reference 11). Actual arching factors have been calculated from interface and soil stress gage results. Average calculated arching and load factors for each test are given in Table 4.3. Actual soil arching factors vary widely between tests.

Theoretical pressure distributions are compared with interface pressure gage results in Figures 4.2 through 4.5. Although the actual load distribution is best described using a fourth-order equation, the parabolic load distribution assumed in the VSBS code compares well with actual loading across the center of the roof span. However, the parabolic loading does not predict the large loads over supports and results in theoretical arching ratios smaller than those calculated from the test data.

Predicted deflections for Tests YE1 and YE4 were much higher than actual deflections, while the predicted deflection for Test YE2 was slightly less than actual deflection. Deflections in Tests YE1 and YE4 were largely elastic, indicating that the VSBS code does not do a good job of predicting stiffness in the elastic region.

The roof in Test YE3 deflected almost three times the predicted value. This increase over the predicted value was probably due to the early-time midspan buckling of the wall.

The computer code RCCOLA (Reference 12) has been used to generate thrust-moment curves for a 2-7/16-inch section of wall both with and without stirrups. Limiting values for concrete and steel strains are $\epsilon_u = 0.004$ and

$\varepsilon_y = f_y/29 \times 10^6$, respectively, Where f_y is the yield strength of reinforcement. Curve plots are shown in Figure 4.6. The shaded and hatched areas shown are bordered by thrust-moment curves generated using (1) static material strengths and (2) dynamic material strengths equal to 1.3 times the static values. Actual moment-thrust curves for Test YE1 and Test YE3 walls should fall within these areas. As can be seen, adding stirrups at 1-1/2-inch centers significantly increases the capacity of the wall under large compressive loads. Wall buckling in Test 3 was probably due to a combination of decreased wall capacity and ductility and a slight increase in overpressure.

4.4 YIELD EFFECTS

The VSBS program (Reference 4) was used to determine peak overpressures for weapon yields that would cause the same maximum deflection as a 9.5-KT weapon at 120 psi. Results have been used to plot the isodamage curve shown in Figure 4.7. Each point on the curve represents a yield and overpressure for a constant magnitude of deflection. Yield and overpressure for Tests YE1 and YE4 are shown for comparison. The 0.5-KT simulation at 162 psi falls just under the curve. Total deflection for this test was 0.63 inch. Total deflection for the baseline tests was 0.71 inch. Based on the results of these two tests, the VSBS program appears to be an accurate method for predicting variations in yield and overpressure required to cause a specified level of damage.

An isodamage curve for the 16-KT, 50-psi damage level was generated for the 1/4-scale structure and is shown in Figure 4.8. Required overpressure for a 0.12-KT yield is 65 psi. Based on VSBS predictions, the prototype Keyworker shelter should have been placed at 65 psi in the 8-KT simulation MINOR SCALE Event to sustain damage equivalent to that caused by a 1-MT detonation at 50-psi peak overpressure. Based on test results, it was estimated that the peak overpressures should be increased by approximately 50 percent if the prototype weapon yield is reduced from 1 MT to 8 KT to result in the same damage level. Therefore, the prototype shelter was placed at approximately the 75-psi peak overpressure level (a 50-percent increase in peak overpressure) in the MINOR SCALE Event to sustain the same damage as in a 1-MT, 50-psi test.

Table 4.1. Weapon simulations.

Test	Gage	Yield KT	Maximum Overpressure psi
YE1	BP-1	11.9	125
	BP-2	9.2	122
	BP-3	9.5	130
	BP-4	4.3	104
	BP-5	12.0	127
	BP-6	11.8	111
	Average	9.5	120
YE2	BP-1	1.6	174
	BP-2	1.8	206
	BP-3	2.8	189
	BP-5	2.9	171
	BP-6	1.6	185
	Average	2.1	184
YE3	BP-1	10.7	132
	BP-2	9.2	134
	BP-3	14.5	131
	BP-4	9.3	130
	BP-5	7.3	113
	BP-6	10.2	128
	Average	10.0	128
YE4	BP-1	0.6	163
	BP-2	0.4	163
	BP-3	0.6	181
	BP-4	0.4	139
	Average	0.5	162

Table 4.2. Theoretical and test deflections.

Test	Loading: Weapon Yield KT	Loading: Peak Overpressure psi	Midspan Deflection: Predicted in	Midspan Deflection: Actual Maximum in	Midspan Deflection: Actual Permanent in
YE1	9.5	120	3.02	0.71	0.41
YE2	2.1	184	4.02	--	4.50
YE3	10.0	128	3.38	--	9.50
YE4	0.5	162	2.23	0.63	0.25

Table 4.3. Arching and load factors.

Test	Average Test Values Using SE-3: Ca	Average Test Values Using SE-3: K_L	Average Test Values Using SE-5: Ca	Average Test Values Using SE-5: K_L	Theoretical Values: Ca	Theoretical Values: K_L
YE1	0.93	0.25	0.61	0.25	0.59	0.30
YE2	1.42	0.35	--	0.35	0.59	0.30
YE3	--	0.24	--	0.24	0.59	0.30
YE4	0.83	0.46	0.74	0.46	0.59	0.30

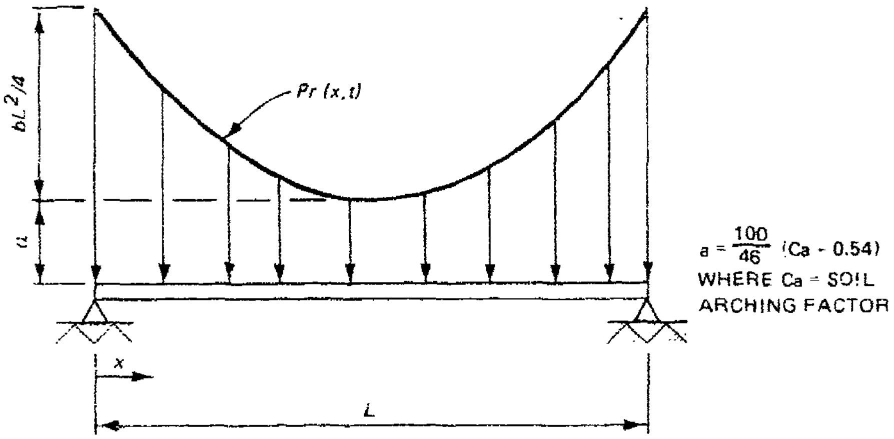
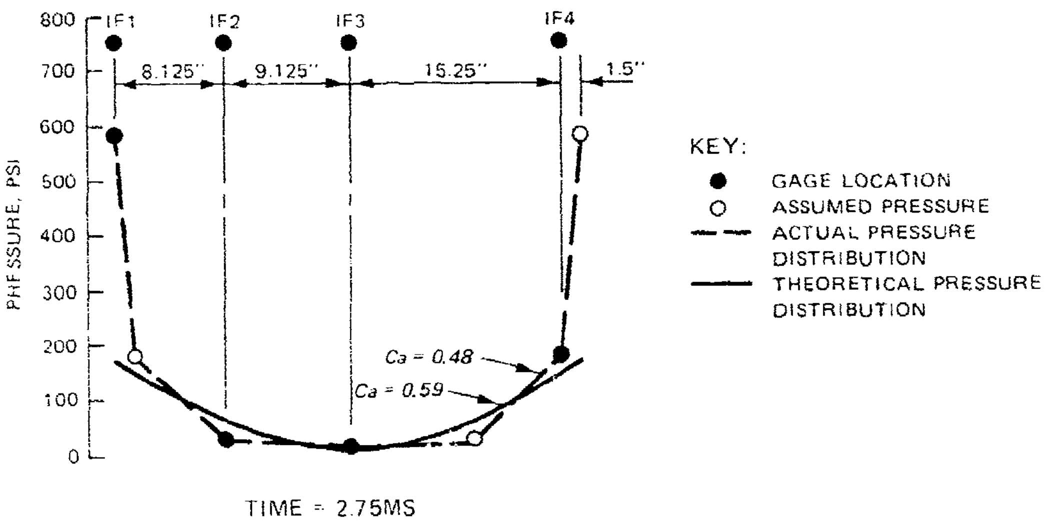


Figure 4.1. Parabolic load distribution.



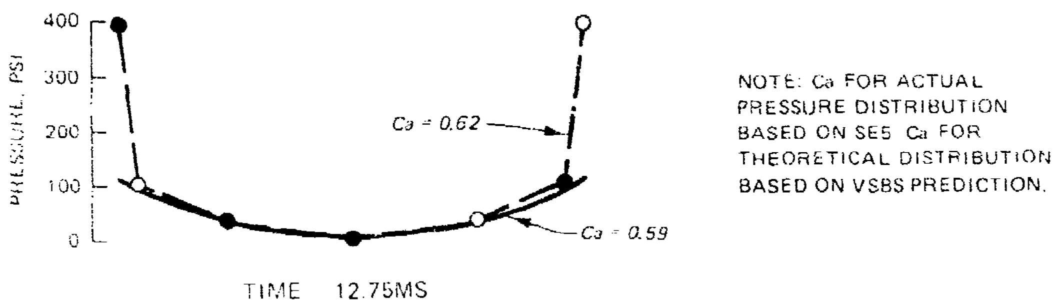
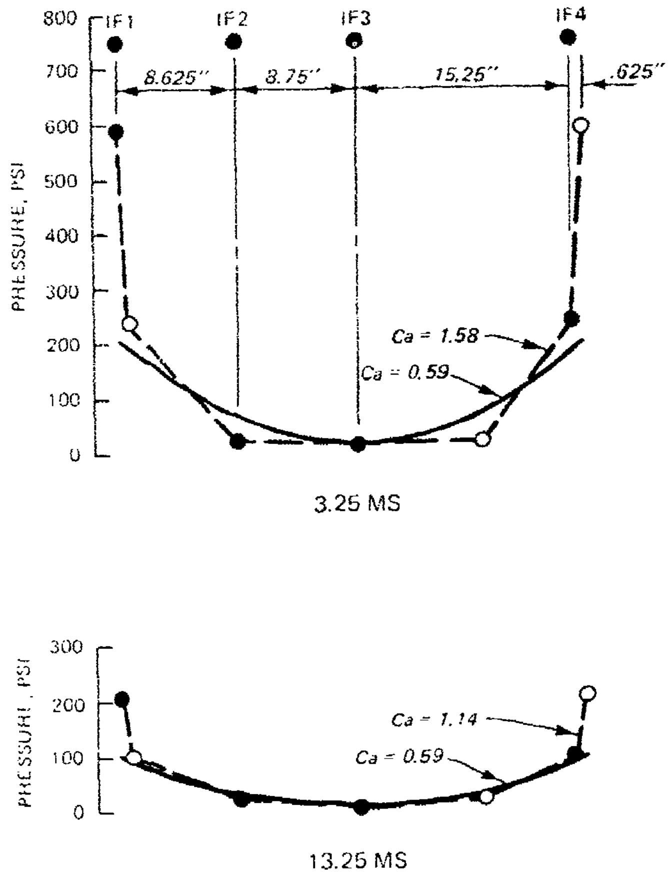


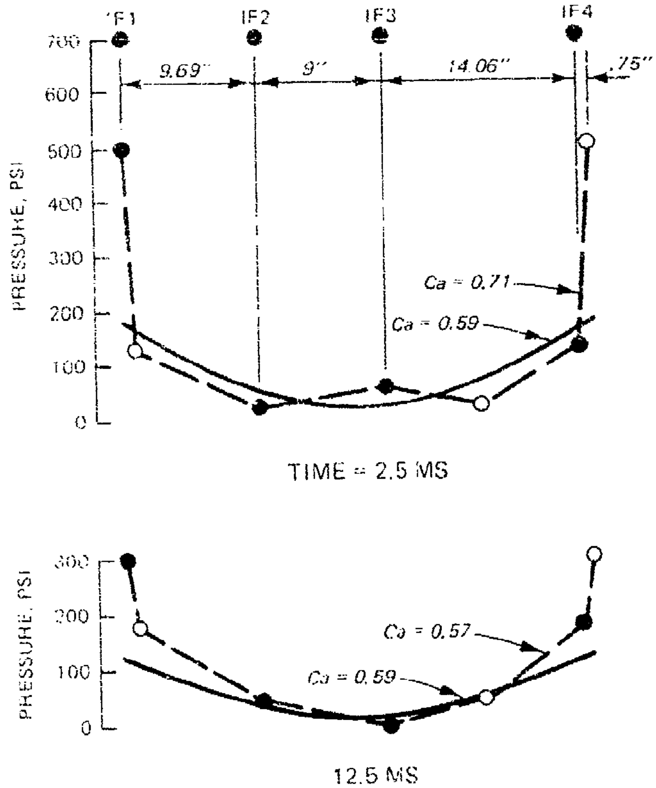
Figure 4.2. Actual and theoretical pressure distributions for Test YE1.



KEY: SEE FIG 4.2

NOTE: Ca FOR ACTUAL PRESSURE DISTRIBUTION BASED ON SE3. Ca FOR THEORETICAL DISTRIBUTION BASED ON VSBS PREDICTION.

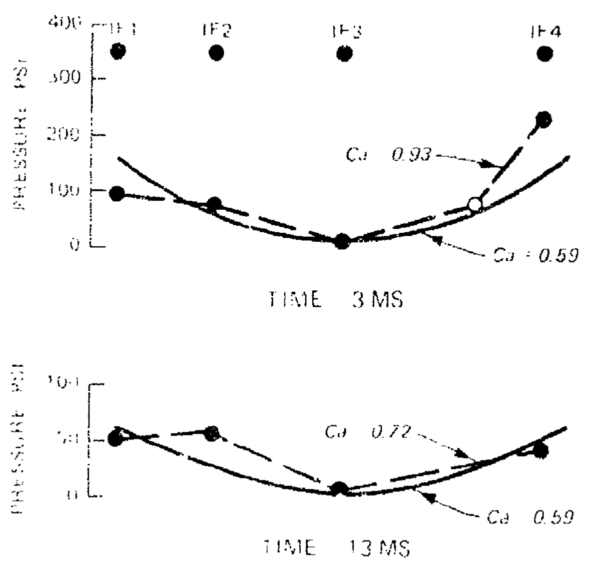
Figure 4.3. Actual and theoretical pressure distributions for Test YE2.



KEY: SEE FIG 4.2

NOTE: Ca FOR ACTUAL PRESSURE DISTRIBUTION BASED ON SE5 FROM TEST 1. Ca FOR THEORETICAL DISTRIBUTION BASED ON USBS PREDICTION.

Figure 4.4. Actual and theoretical pressure distributions for Test YE3.



KEY: SEE FIG 4.2

NOTE: Ca FOR [illegible]UAL PRESSURE DISTRIBUTION BASED ON SE5. Ca FOR THEORETICAL DISTRIBUTION. BASED ON SPEICHER-BRODE WEAPON FIT.

Figure 4.5. Actual and theoretical pressure distributions for Test YE4.

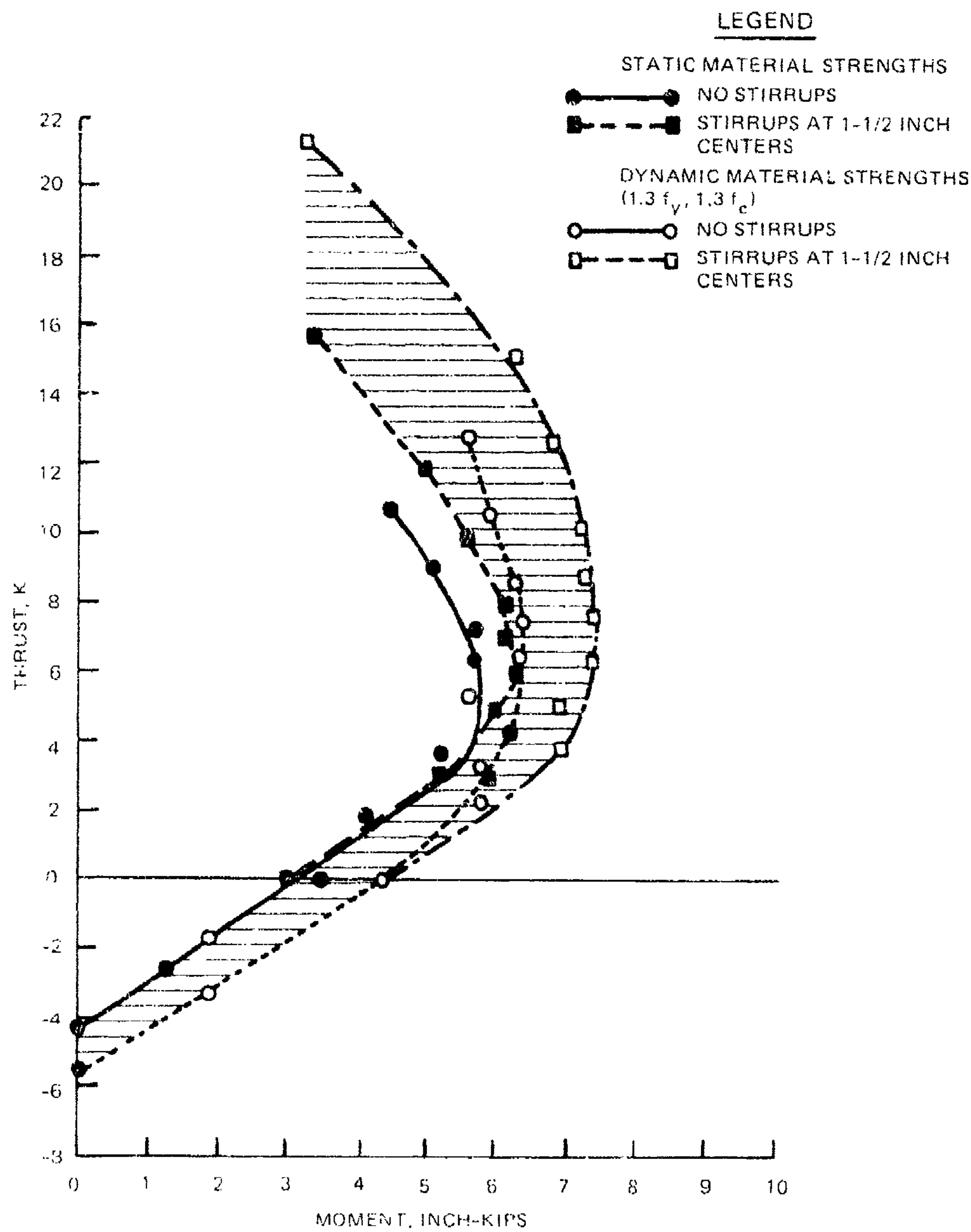


Figure 4.6. Wall moment-thrust curves.

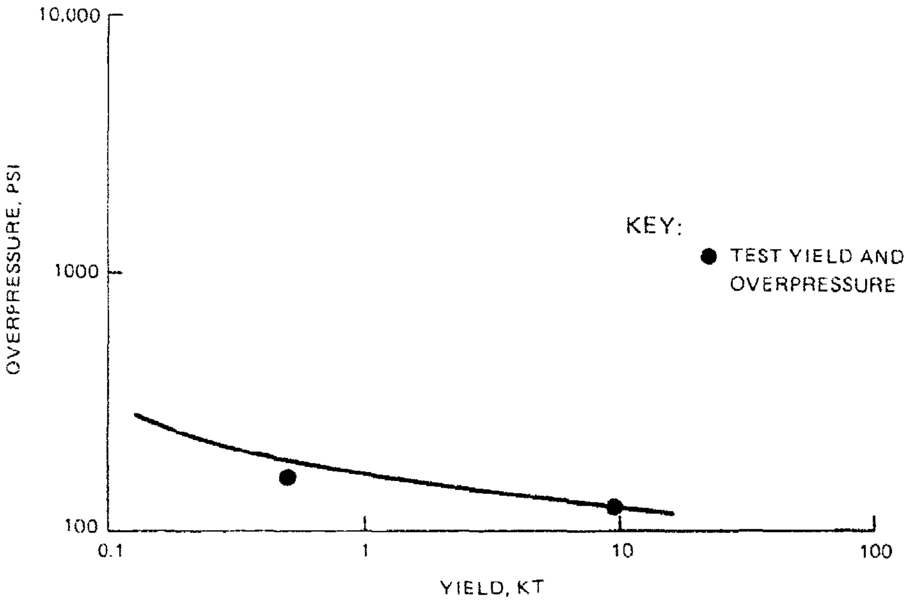


Figure 4.7. Test yield and overpressure plotted against isodamage curve for 9.5-KT, 120-psi damage level.

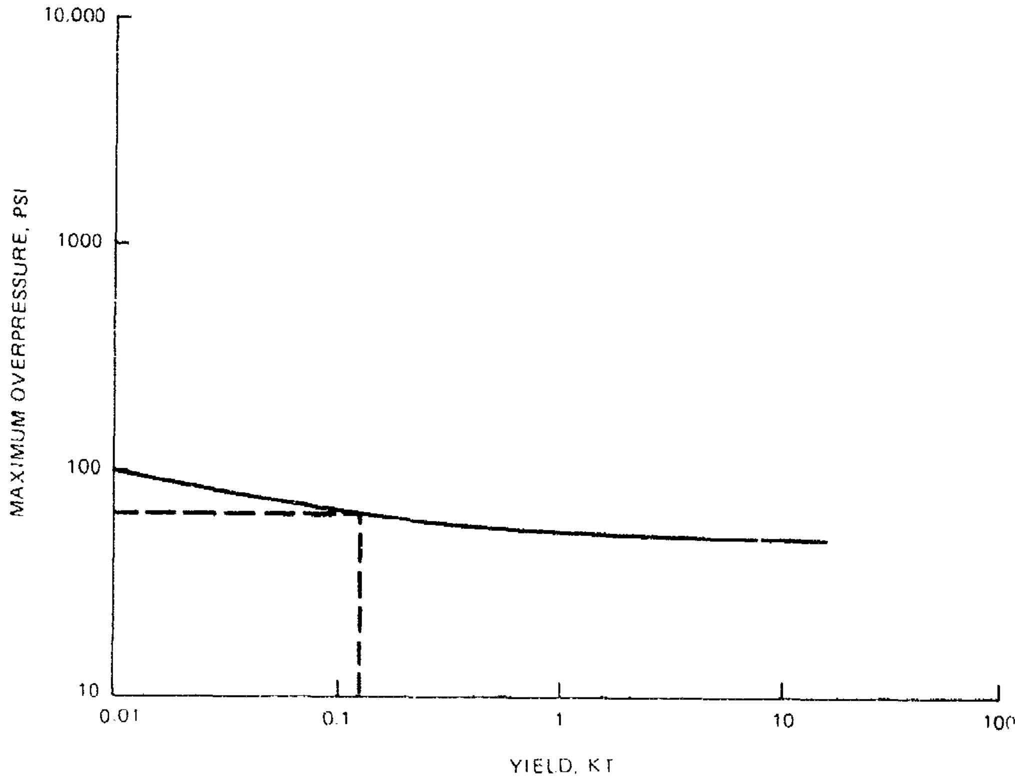


Figure 4.8. Isodamage curve for 16-KT, 50-psi damage level for the 1/4-scale structure.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

The test series showed that the prototype Keyworker shelter should be placed near the 75-psi peak overpressure level in the MINOR SCALE 8-KT event to sustain the same damage as in a 1-MT, 50-psi test.

The test results indicate that the VSBS program can be used to predict peak overpressures required at various yields to result in a constant level of damage. Modification of the resistance function used in the VSBS program is required to better predict small plastic deformations. The load distribution computed in the VSBS program resulted in theoretical roof loading that agreed fairly well with the test data.

While wall stirrups may not be required to prevent failure at the 50-psi level, including them ensures that the wall will not fail prematurely before the roof at higher overpressures.

5.2 RECOMMENDATIONS

Stirrups should not be omitted from the shelter walls. The procedures used in the VSBS code to compute the initial elastic stiffness and/or the initial maximum resistance of the roof slab should be modified to improve its accuracy in predicting some of the small plastic deformations observed in these tests.

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1. T. R. Slawson et al.; "Structural Element Tests in Support of the Keyworker Blast Shelter Program" (in preparation); US Army Engineer Waterways Experiment Station, Vicksburg, Miss.

2. S. C. Woodson; "Effects of Shear Stirrup Details on Ultimate Capacity and Tensile Membrane Behavior of Reinforced Concrete Slabs"; Technical Report SL-85-4, August 1985; US Army Engineer Waterways Experiment Station, Vicksburg, Miss.

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10. J. S. McNulty; "An Experimental Study of Arching in Sand"; Technical Report No. 1-674, May 1965; US Army Engineer Waterways Experiment Station, Vicksburg, Miss.

11. S. A. Kiger; "Static Test of a Hardened Shallow-Buried Structure"; Technical Report N-78-7, October 1978; US Army Engineer Waterways Experiment Station, Vicksburg, Miss.

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APPENDIX A

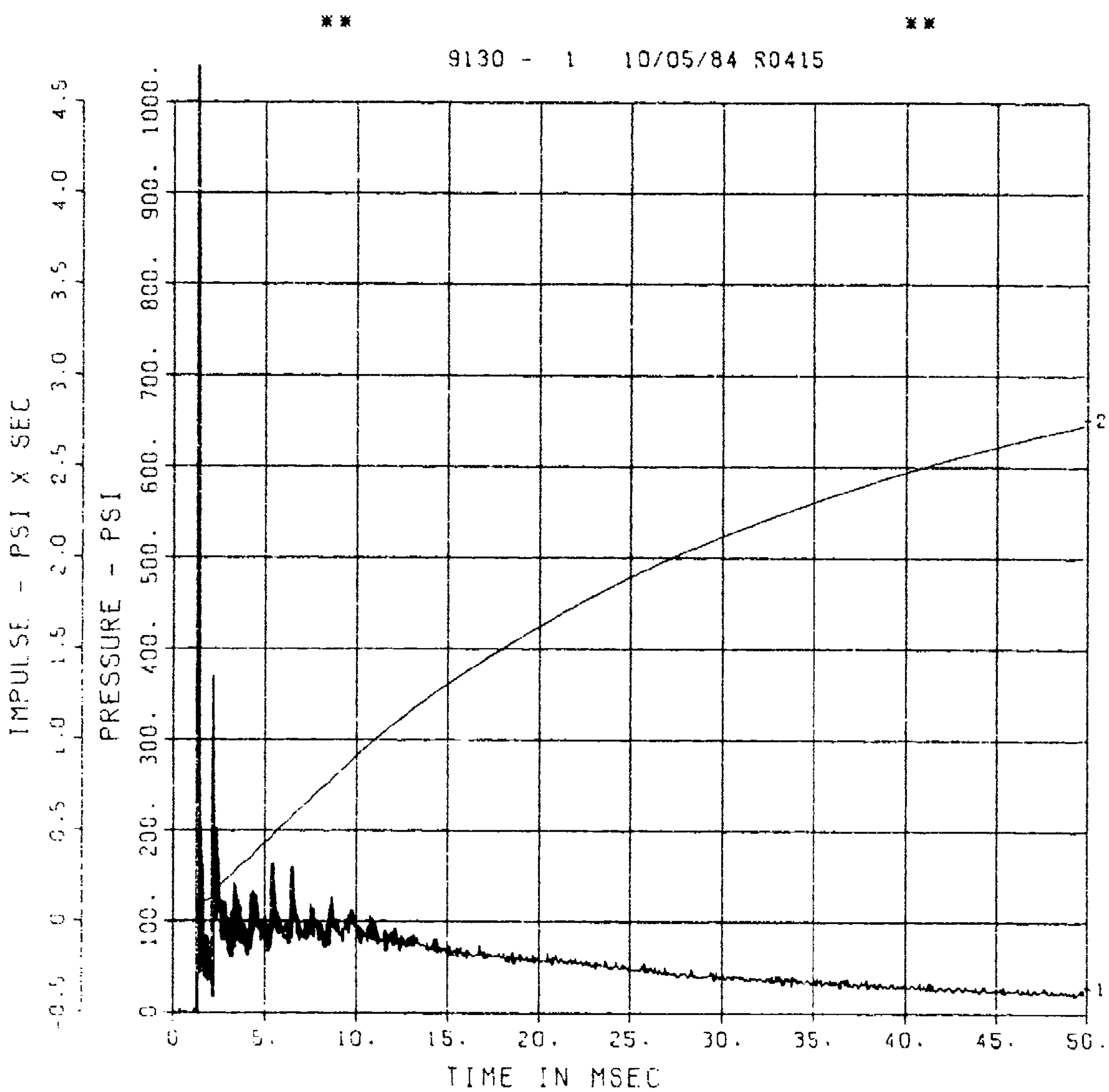
TEST DATA

FEMA YIELD EFFECTS 1

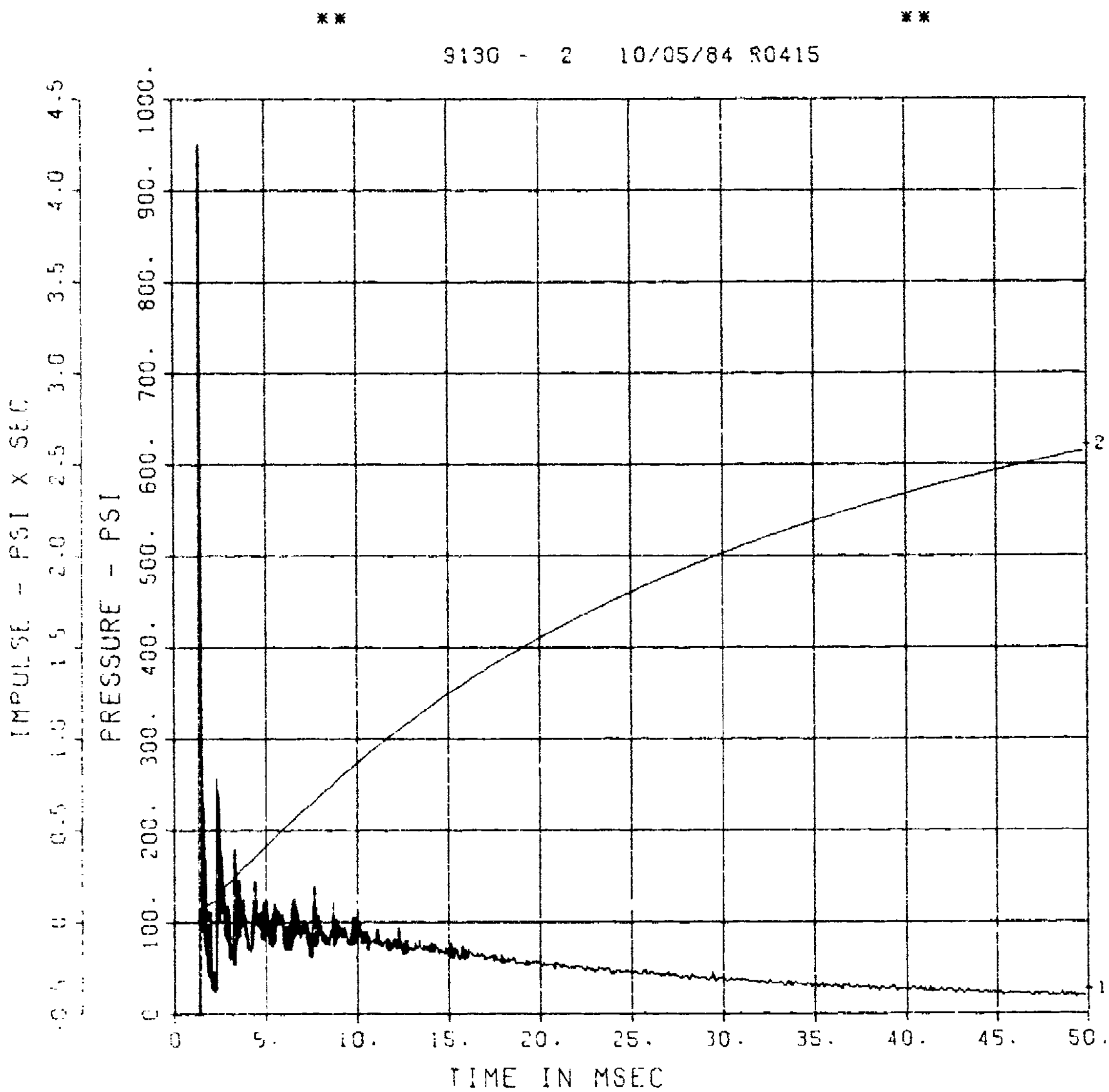
BP-1

200000. HZ CAL= 1120.

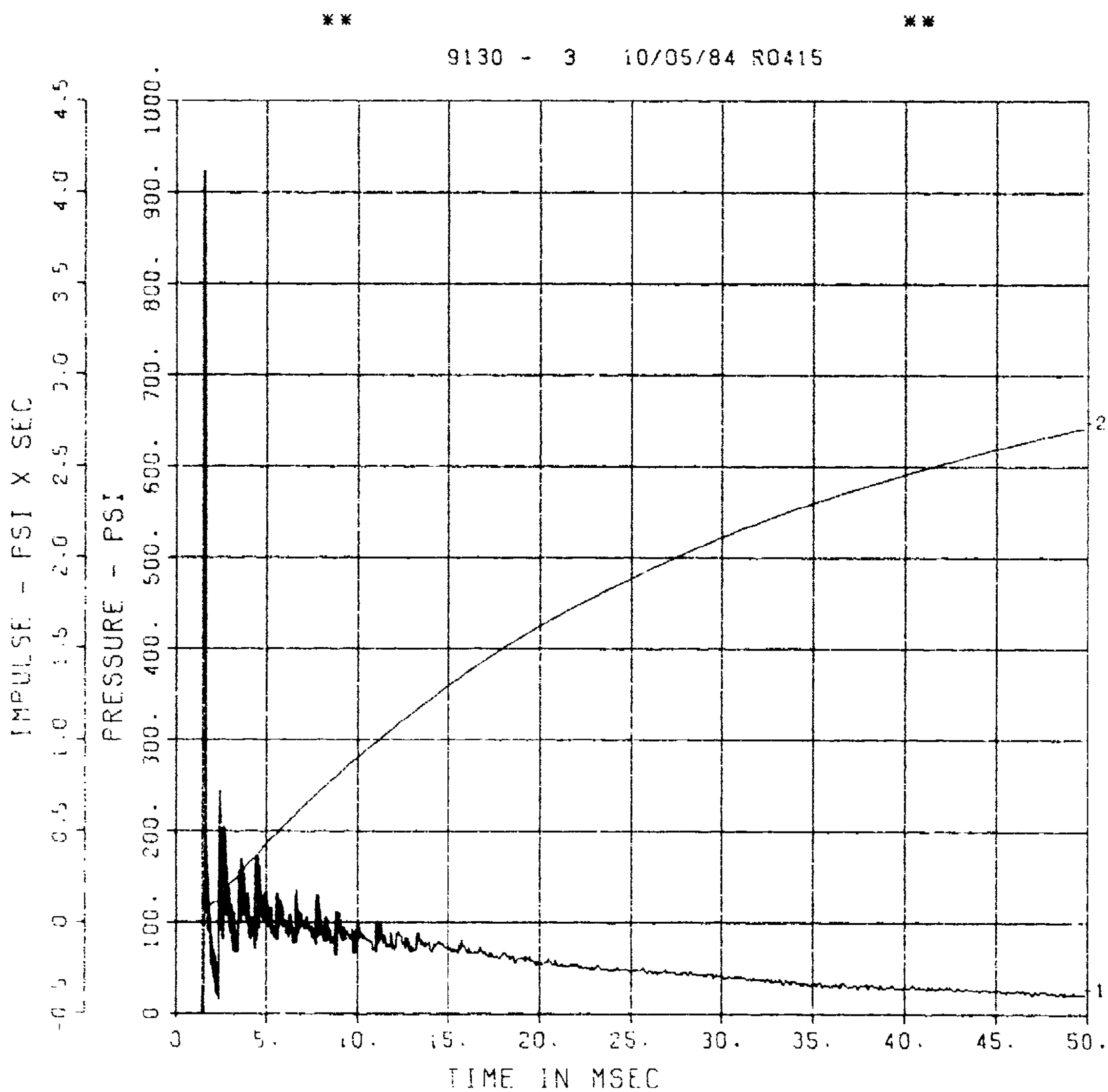
LP2/0 70% CUTOFF= 18000. HZ



FEMA YIELD EFFECTS 1
BP-2
200000. HZ CAL= 933.9
LP2/0 70% CUTOFF= 18000. HZ



FEMA YIELD EFFECTS 1
BP-3
200000. HZ CAL= 810.1
LP2/0 70% CUTOFF= 18000. HZ



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BP-4
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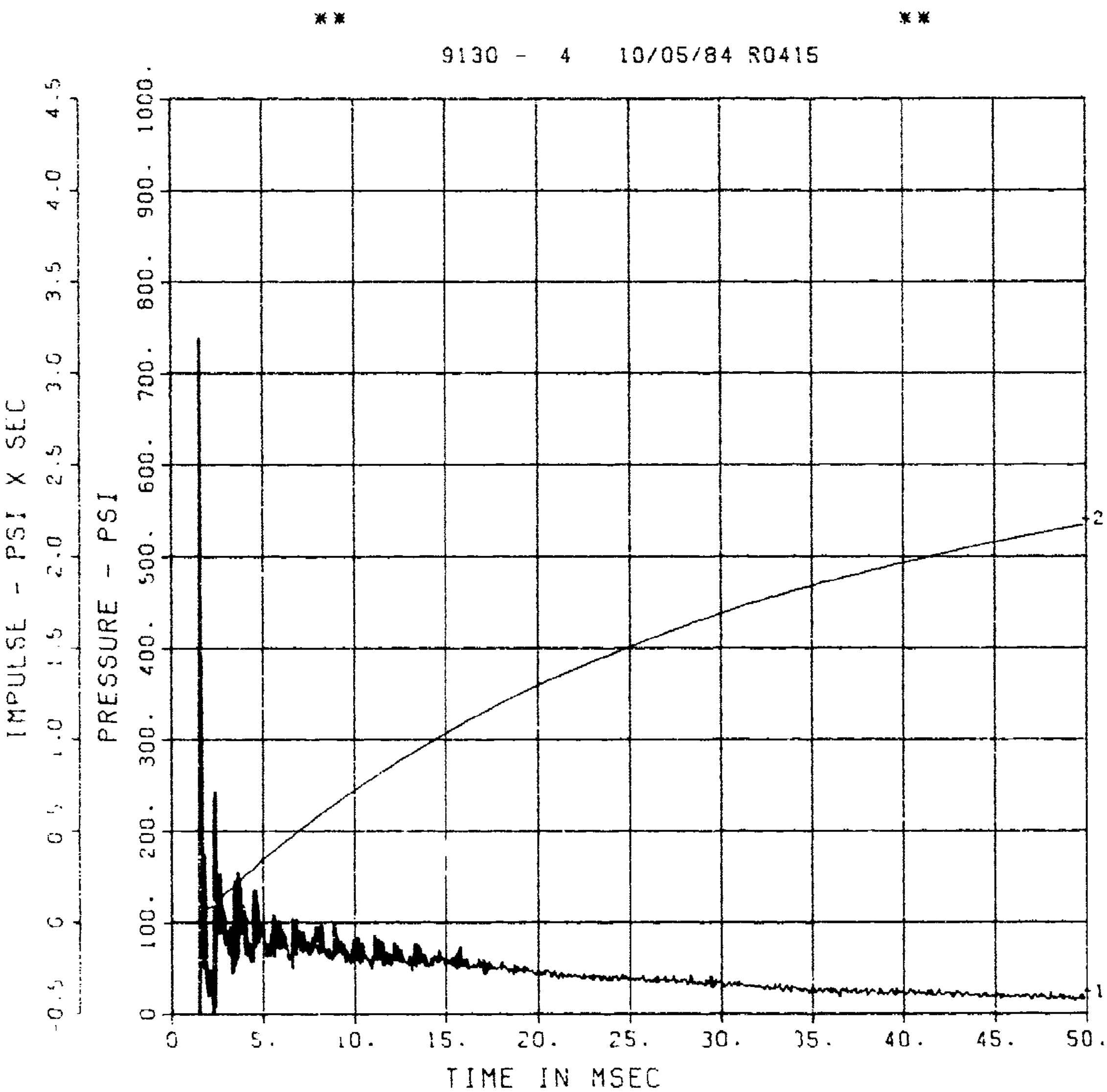
LP2/0 70% CUTOFF= 18000. HZ



FEMA YIELD EFFECTS 1

BP-5

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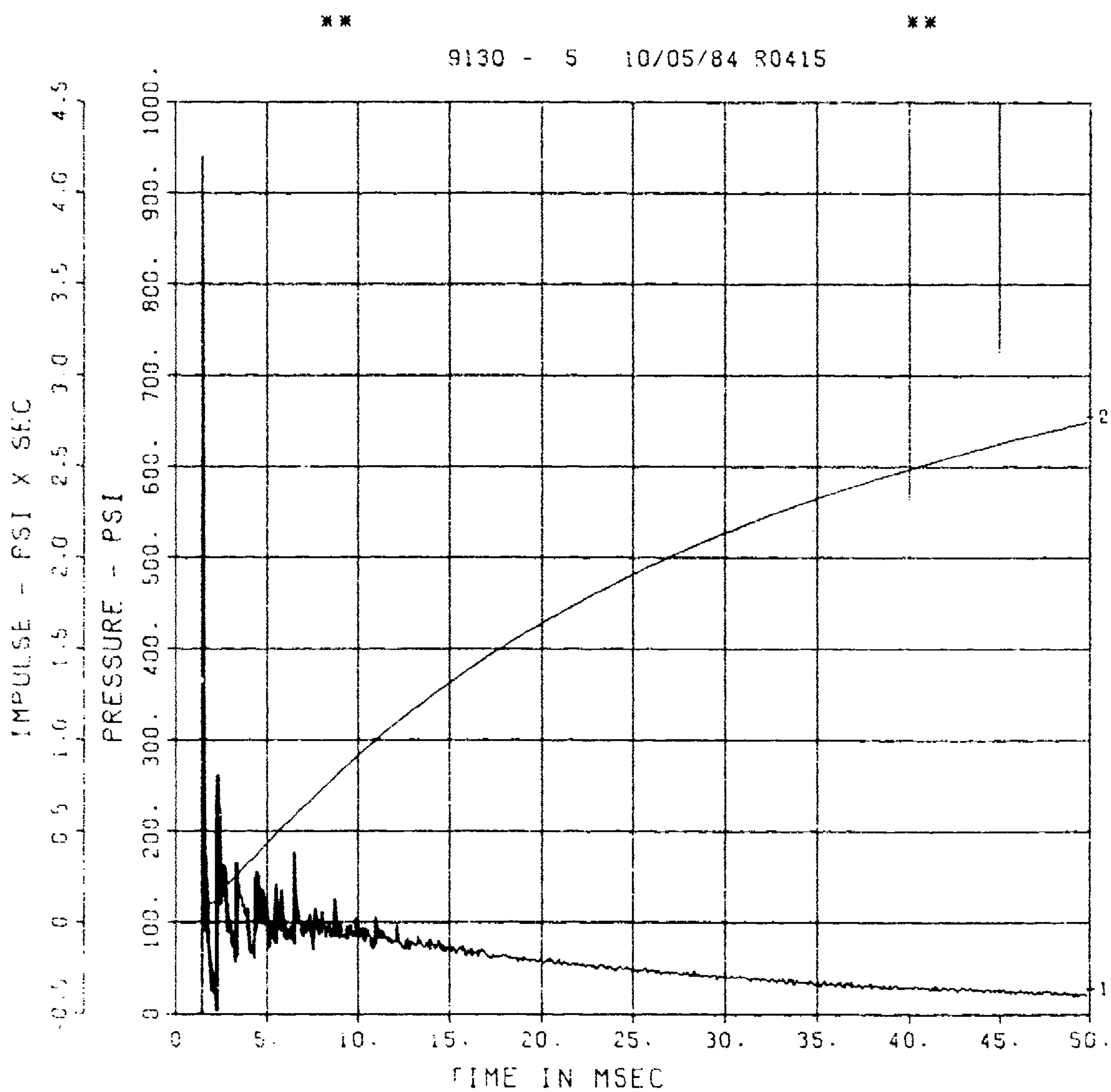
LP2/0 70% CUTOFF= 18000. HZ



FEMA YIELD EFFECTS 1
BP-6
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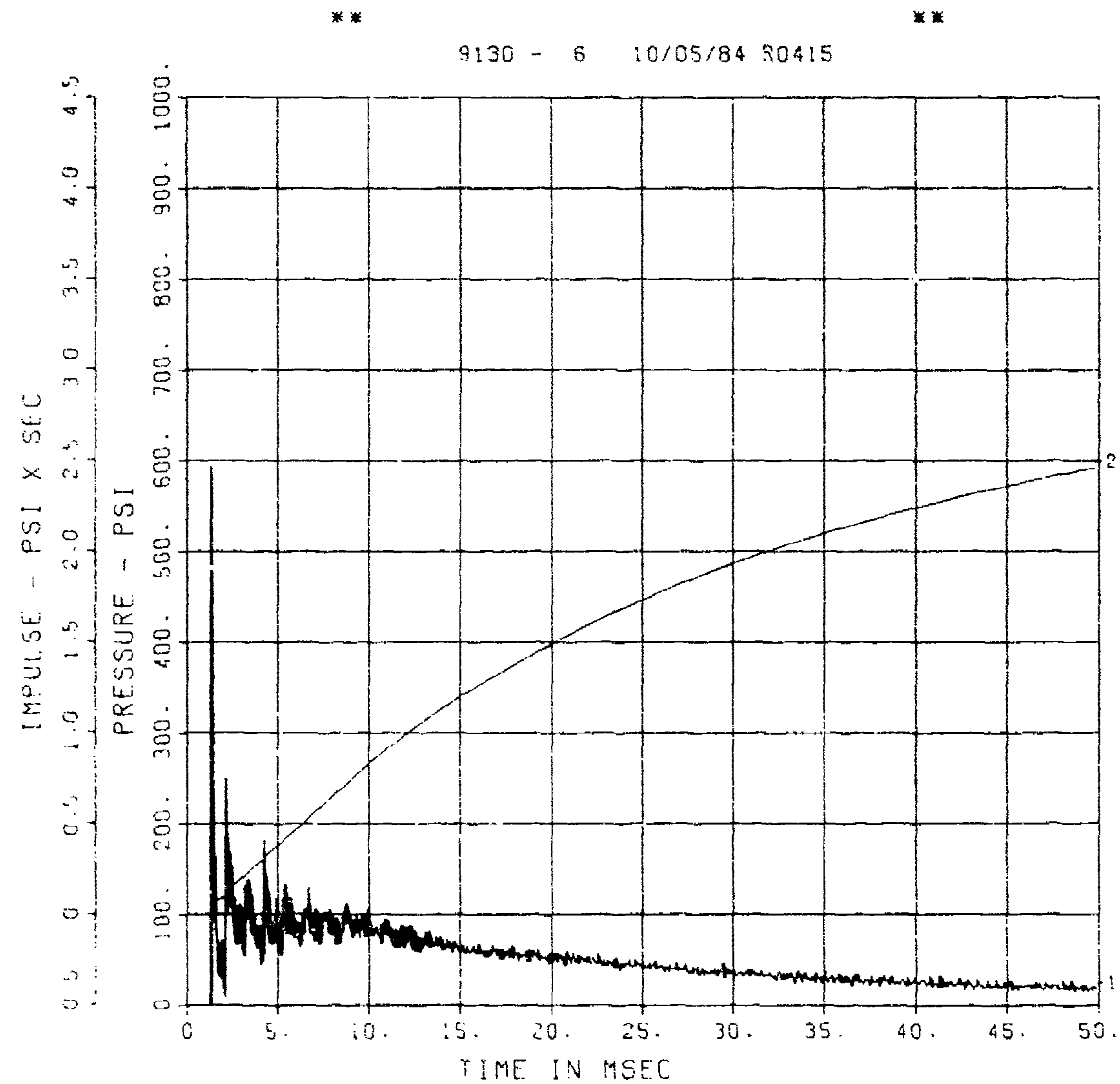
LP2/0 70% CUTOFF= 18000. HZ



FEMA YIELD EFFECTS 1
SE-1
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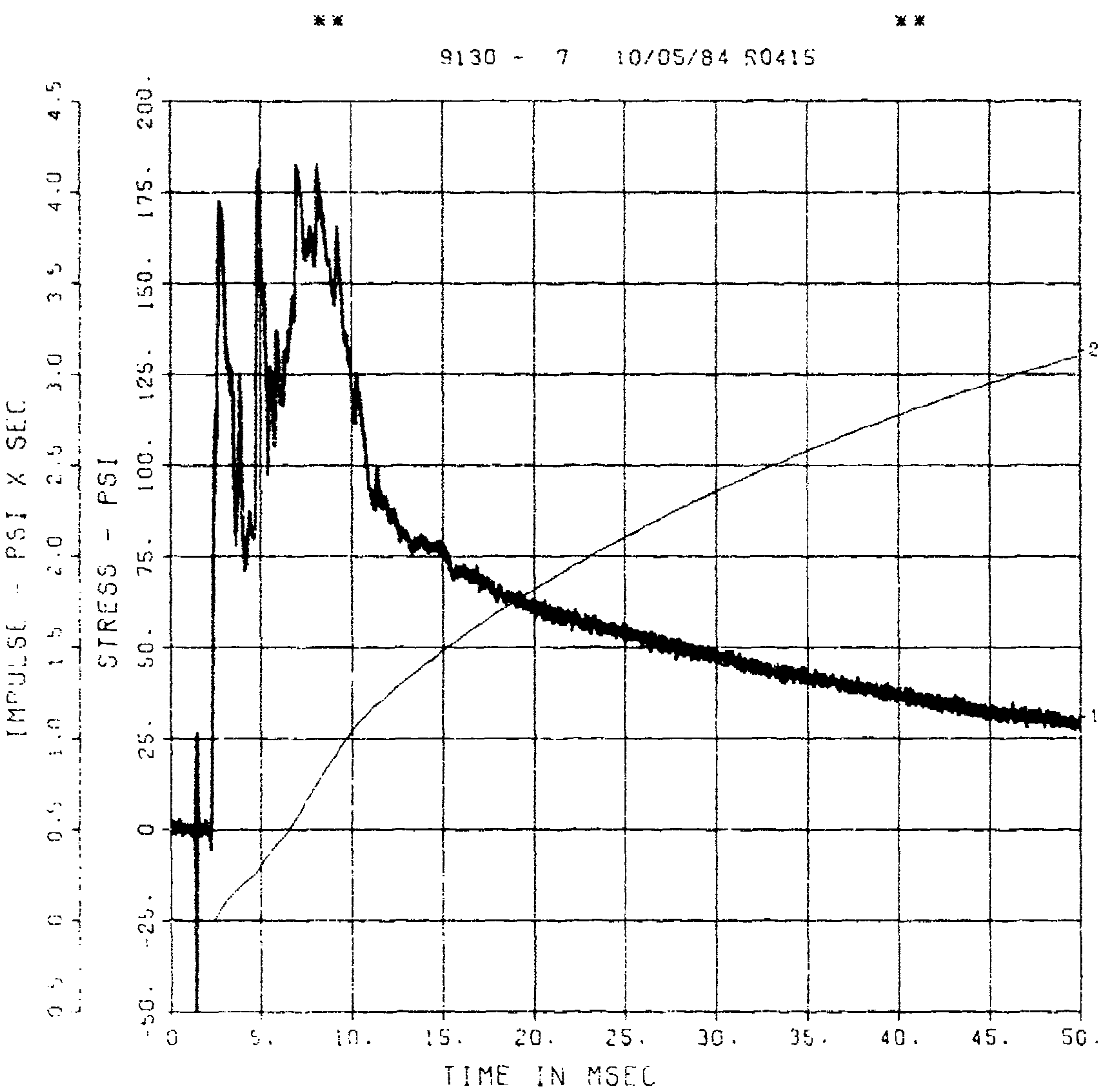

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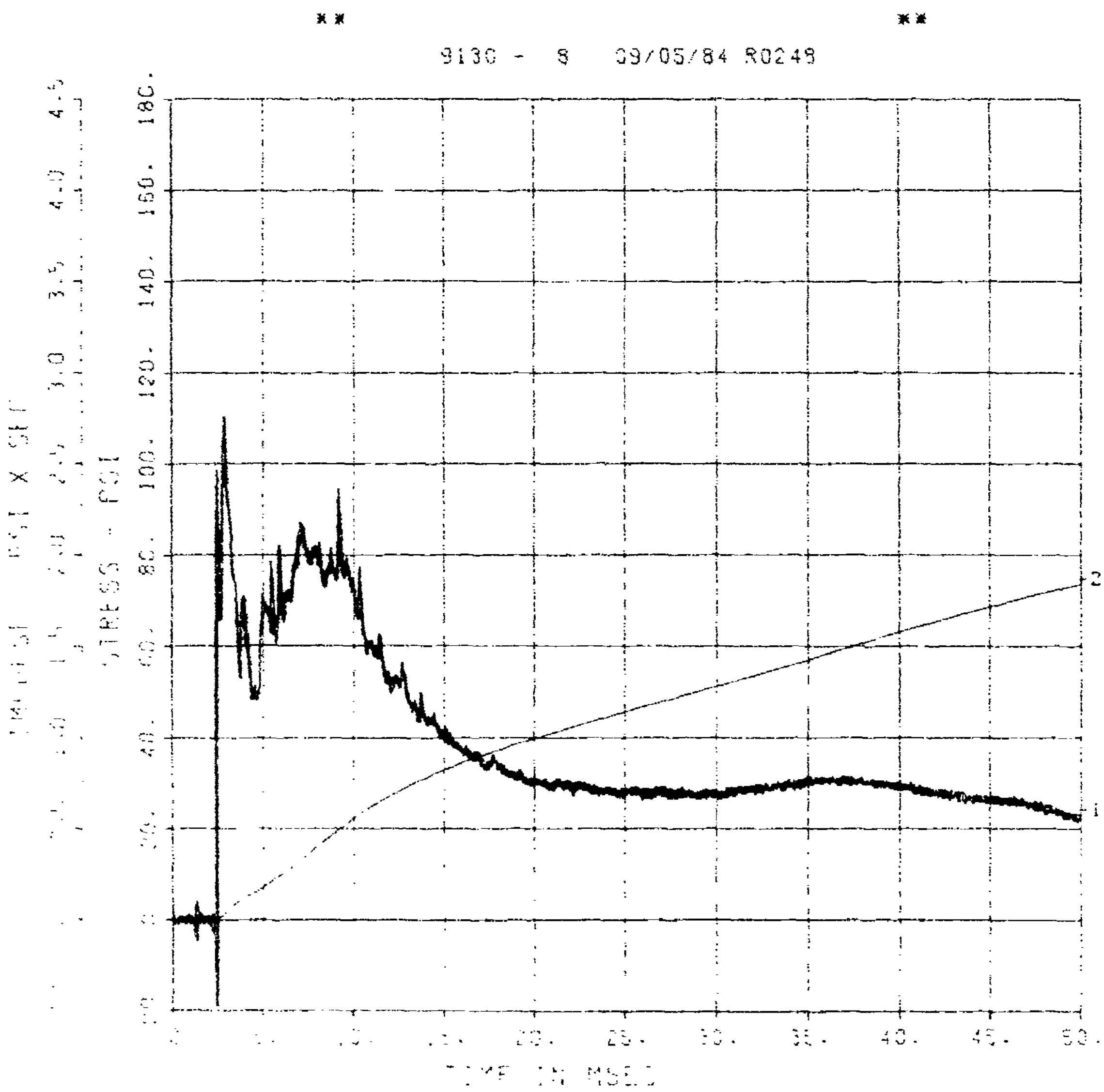
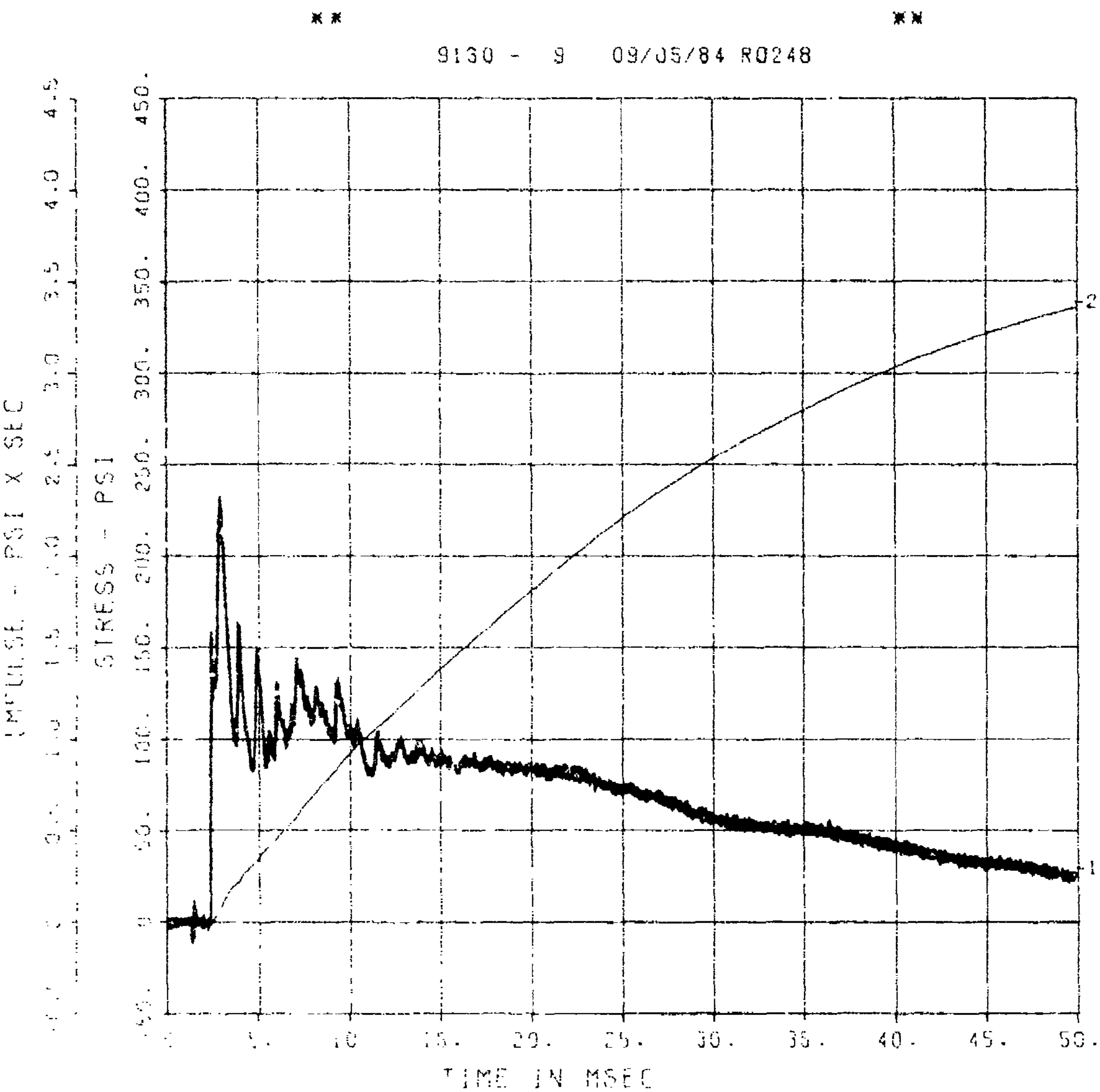
SE-2
200000. HZ CAL= 173.7



FEMA YIELD EFFECTS 1

SE-3

200000. HZ CAL= 311.8



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SE-4
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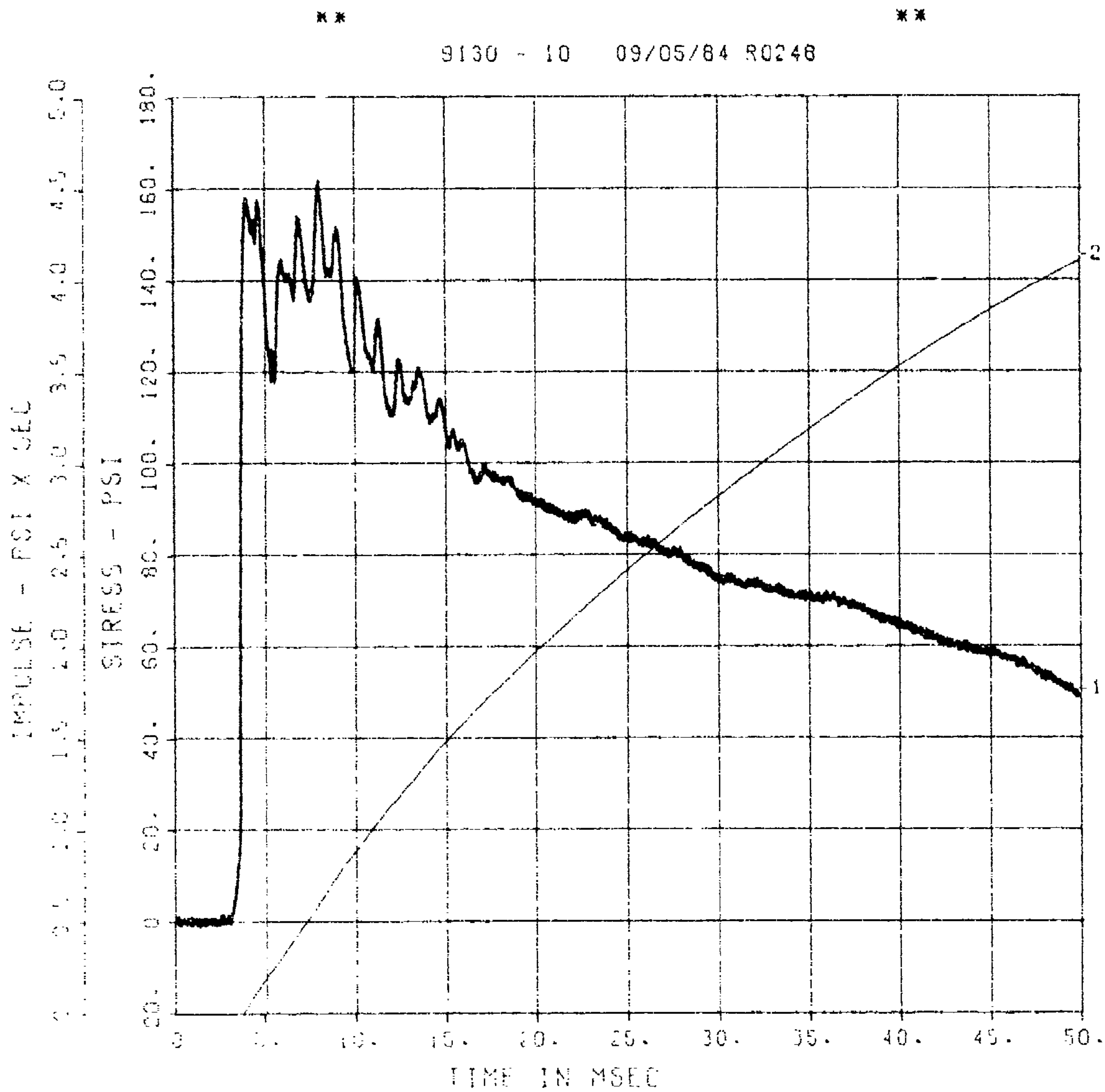

FEMA YIELD EFFECTS 1
SE-5
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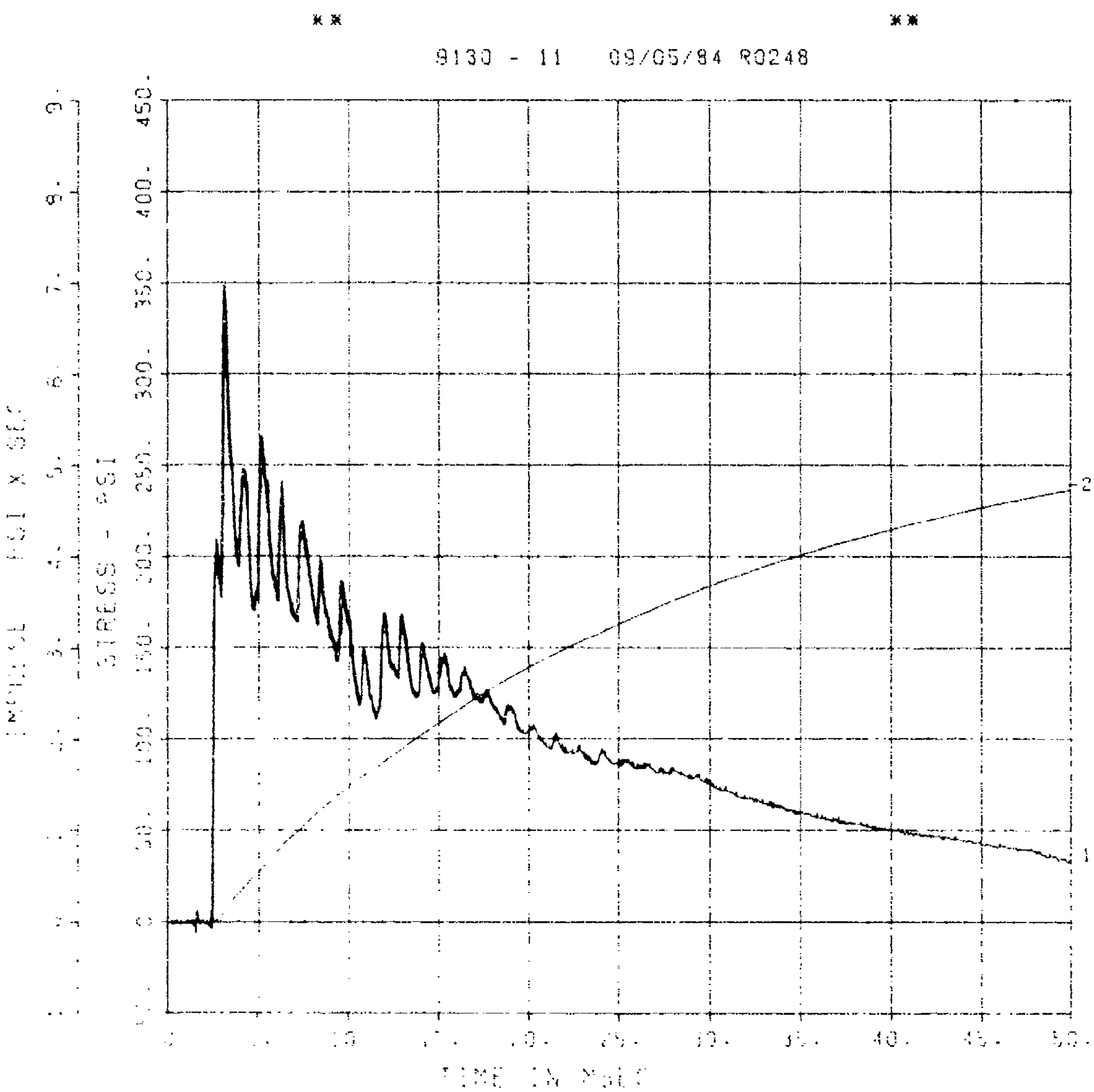

FEMA YIELD EFFECTS 1
SE-7
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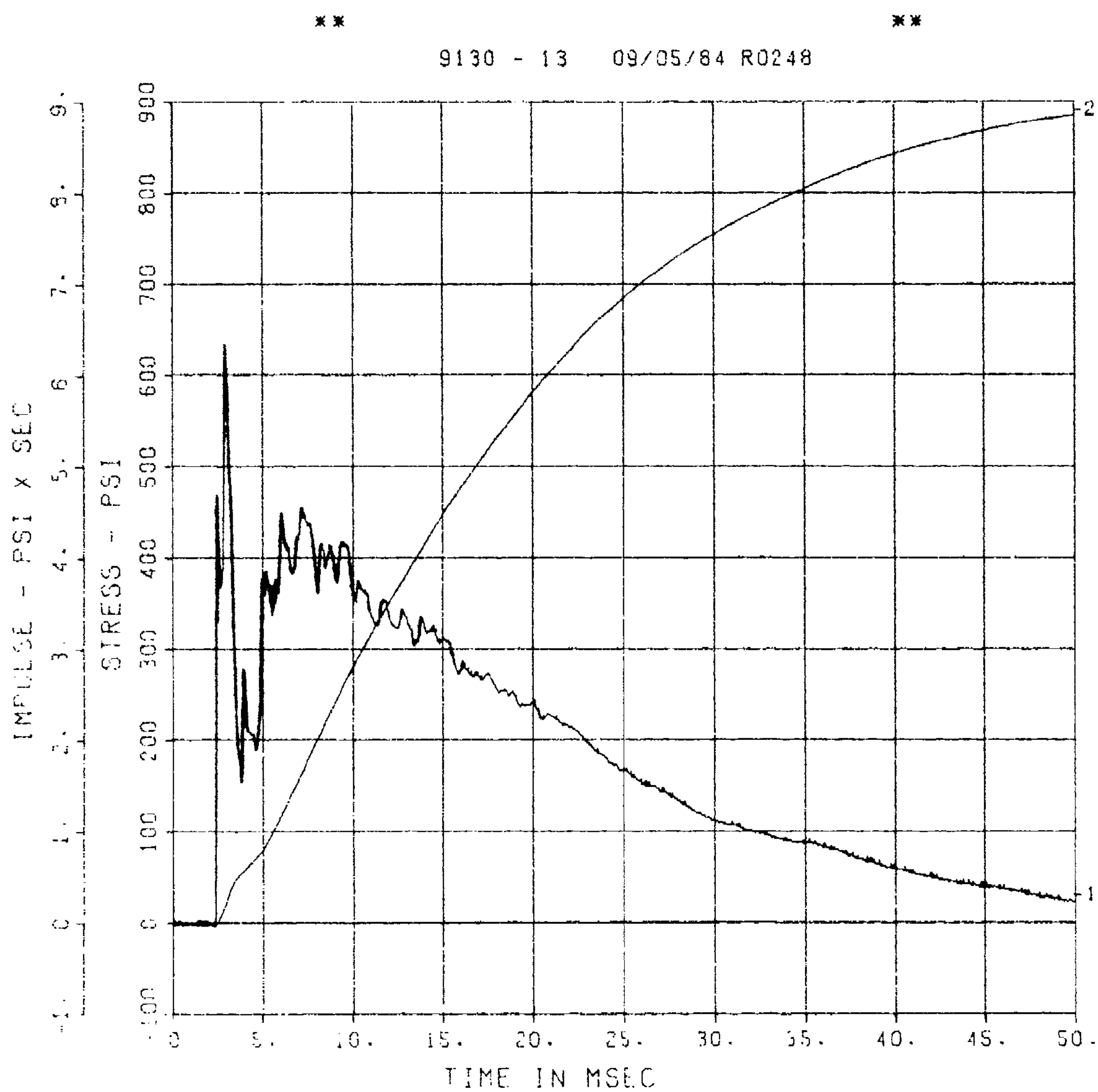
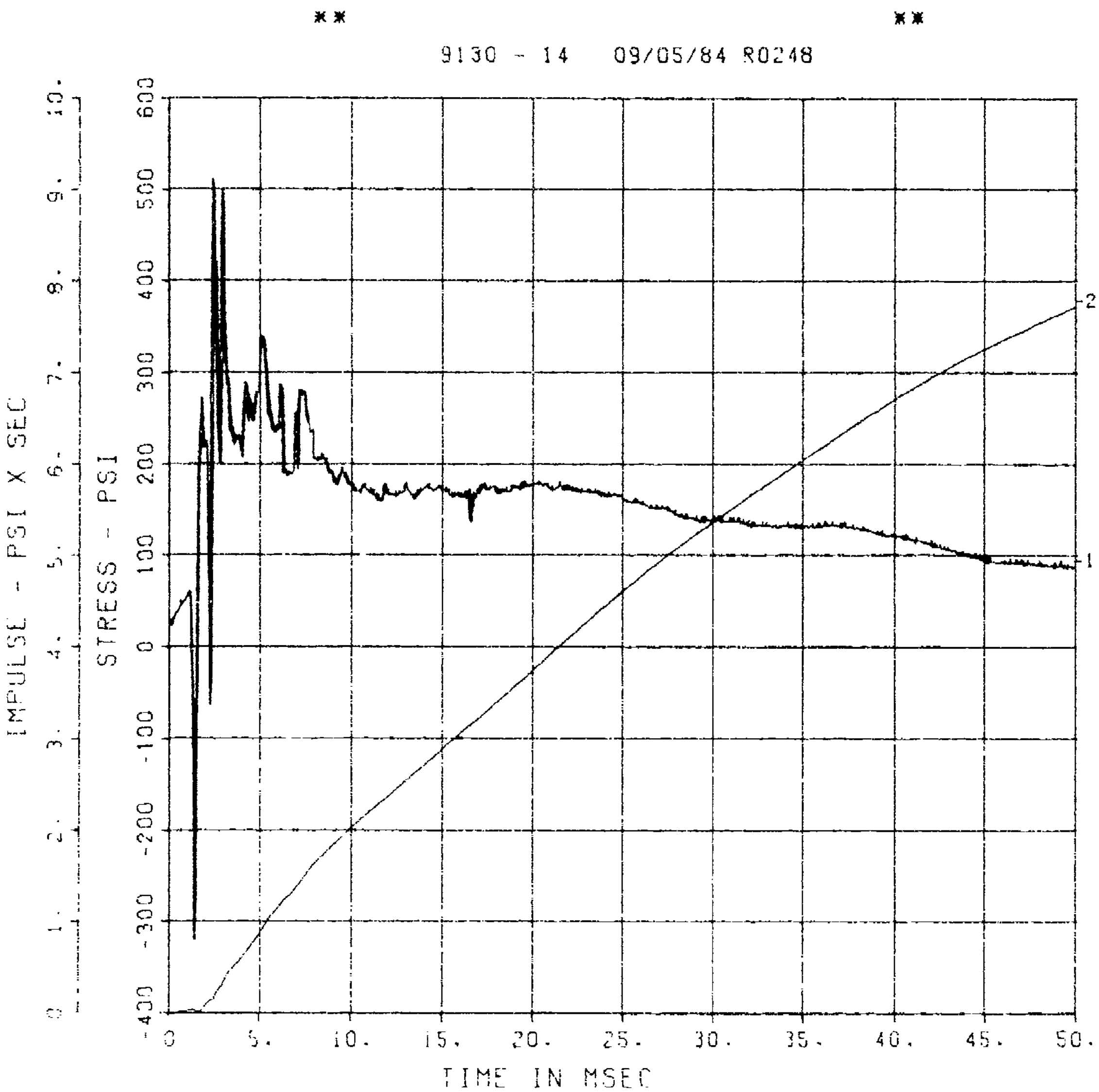


FEMA YIELD EFFECTS 1
SE-8
200000. HZ CAL= 403.3



FEMA YIELD EFFECTS 1
SE-9
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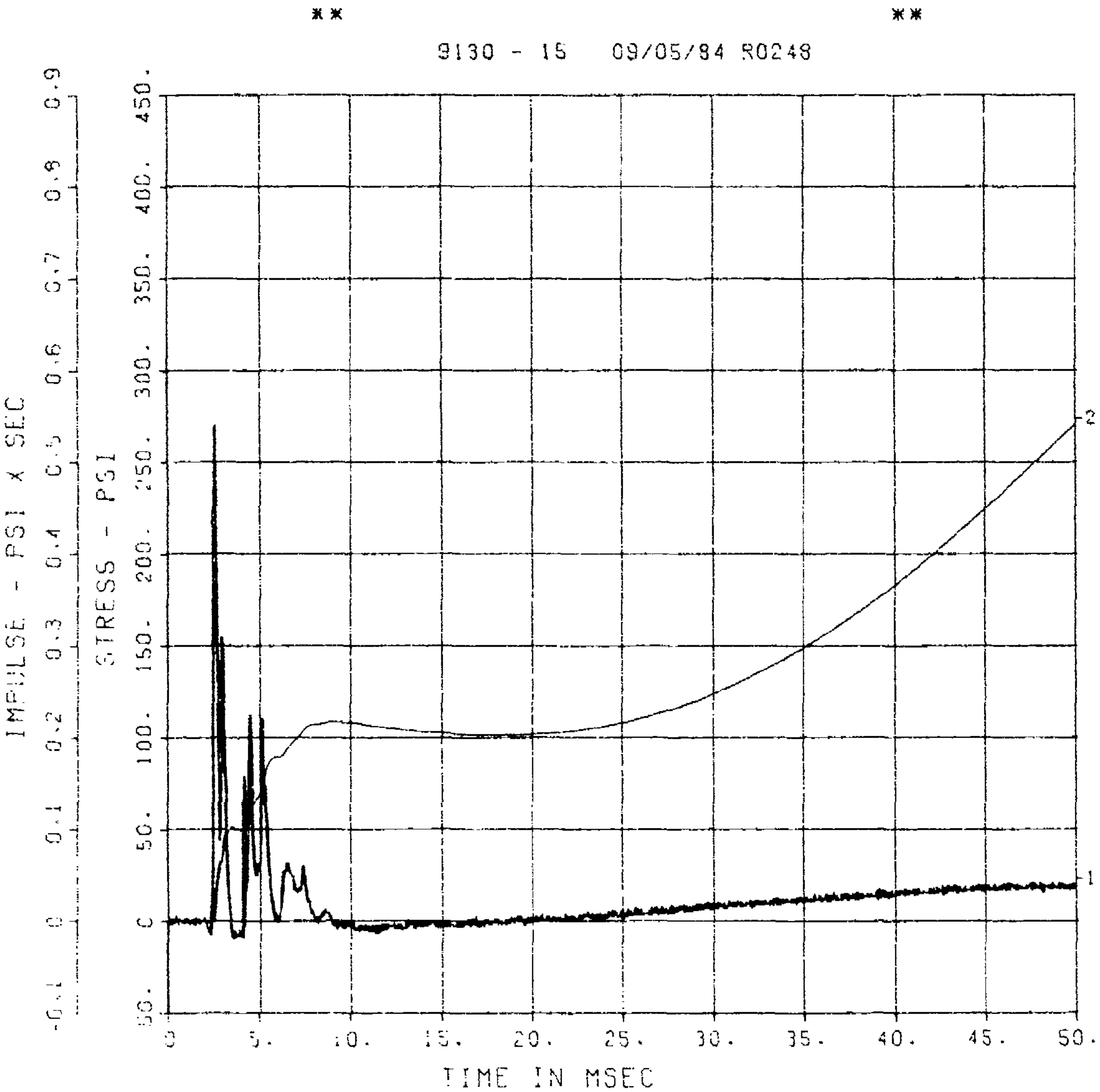

FEMA YIELD EFFECTS 1

AFF-1

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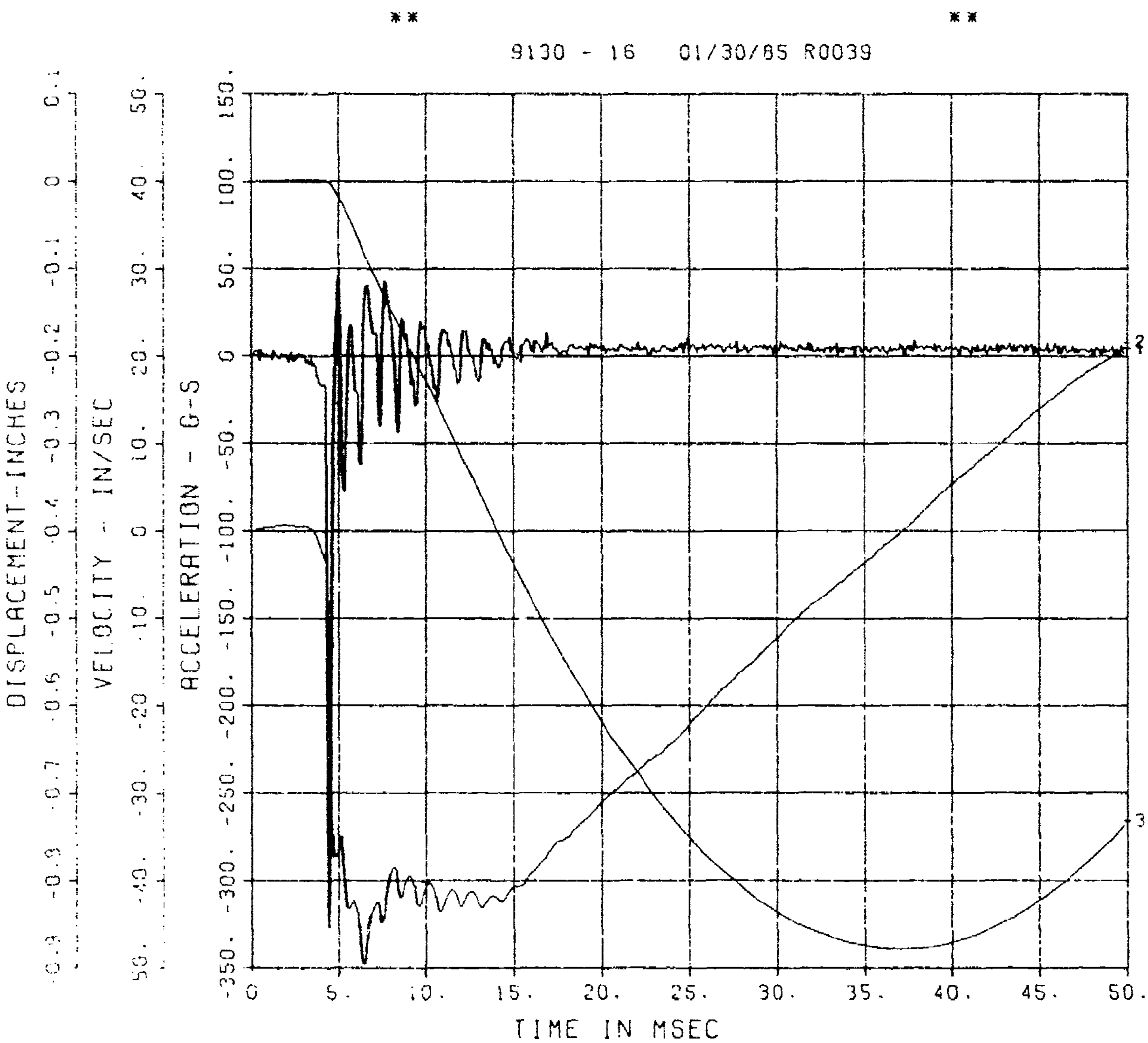
LP4/0 70% CUTOFF= 9000. HZ



FEMA YIELD EFFECTS 1

A-1

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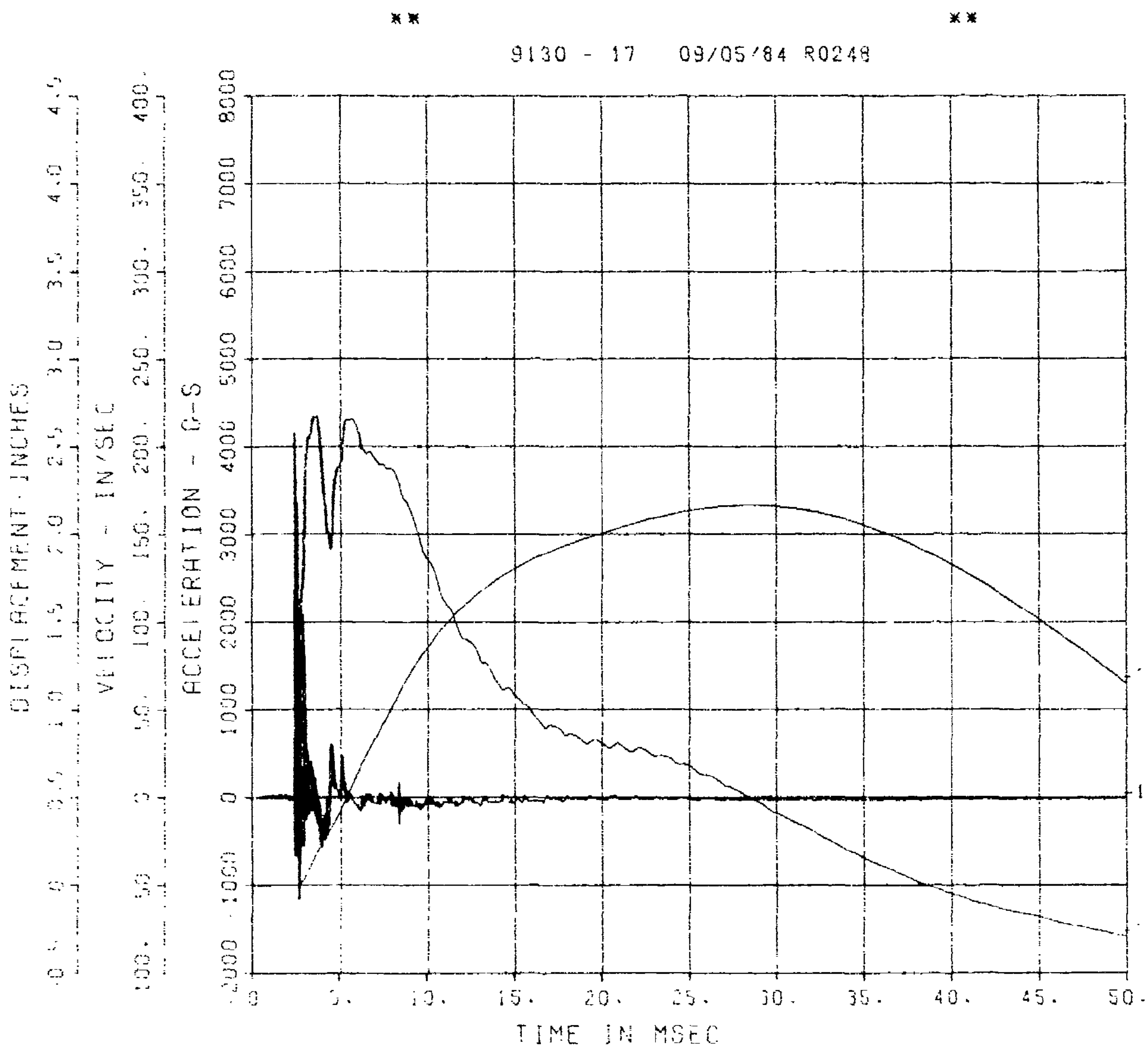

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A-2
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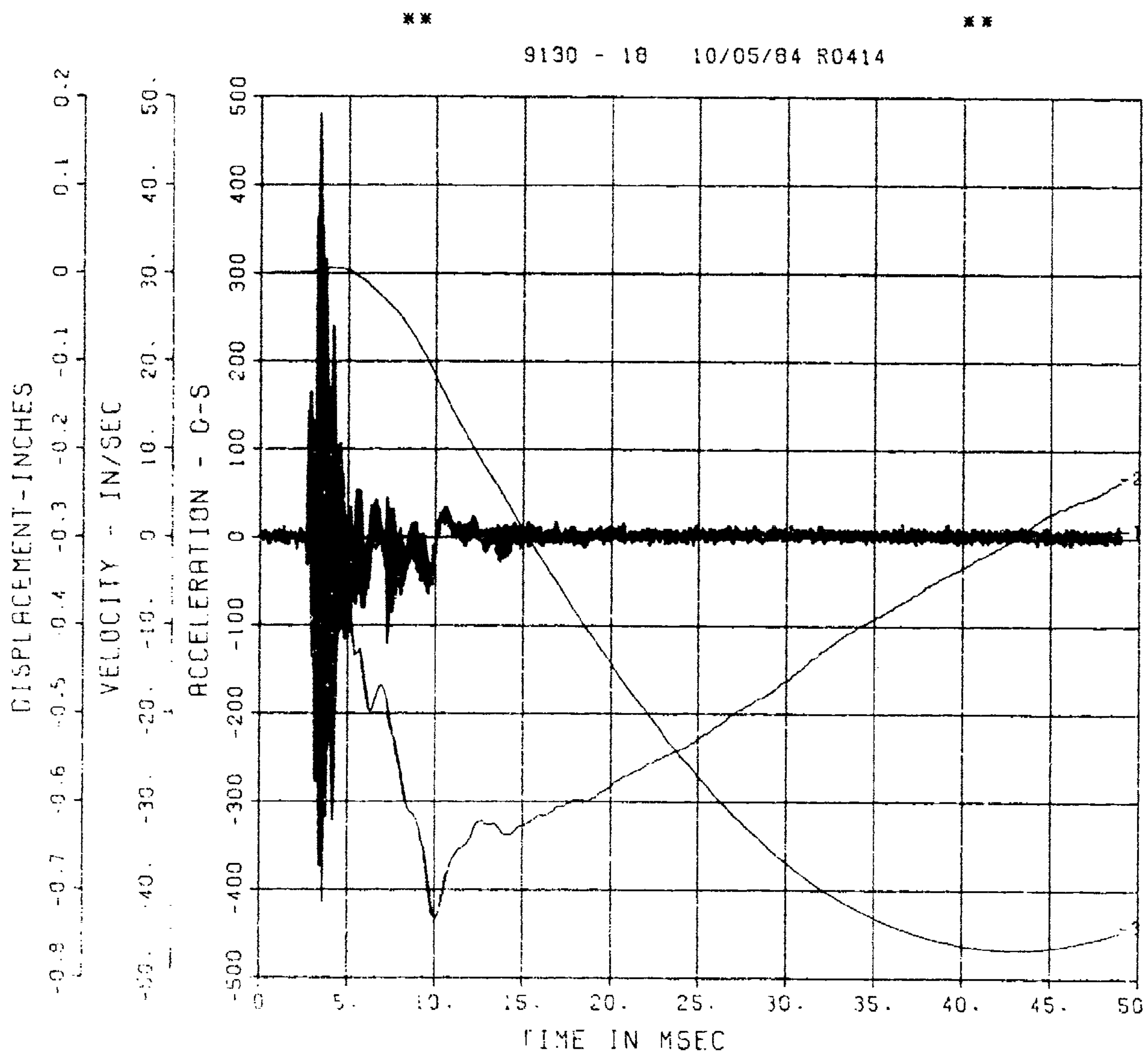

FEMA YIELD EFFECTS 1
A-2
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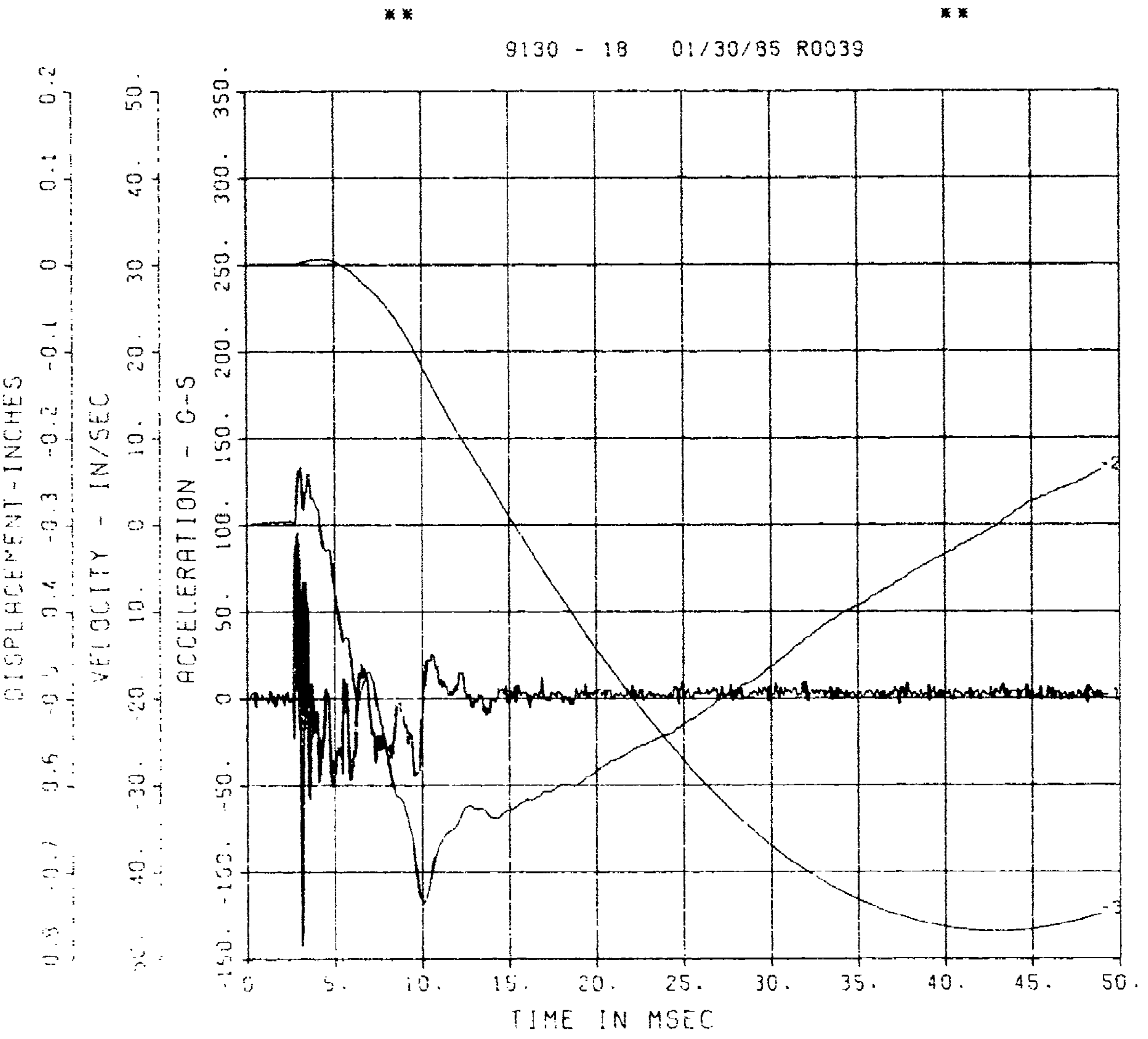
LP4/0 70% CUTOFF= 9000. HZ



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IF-1
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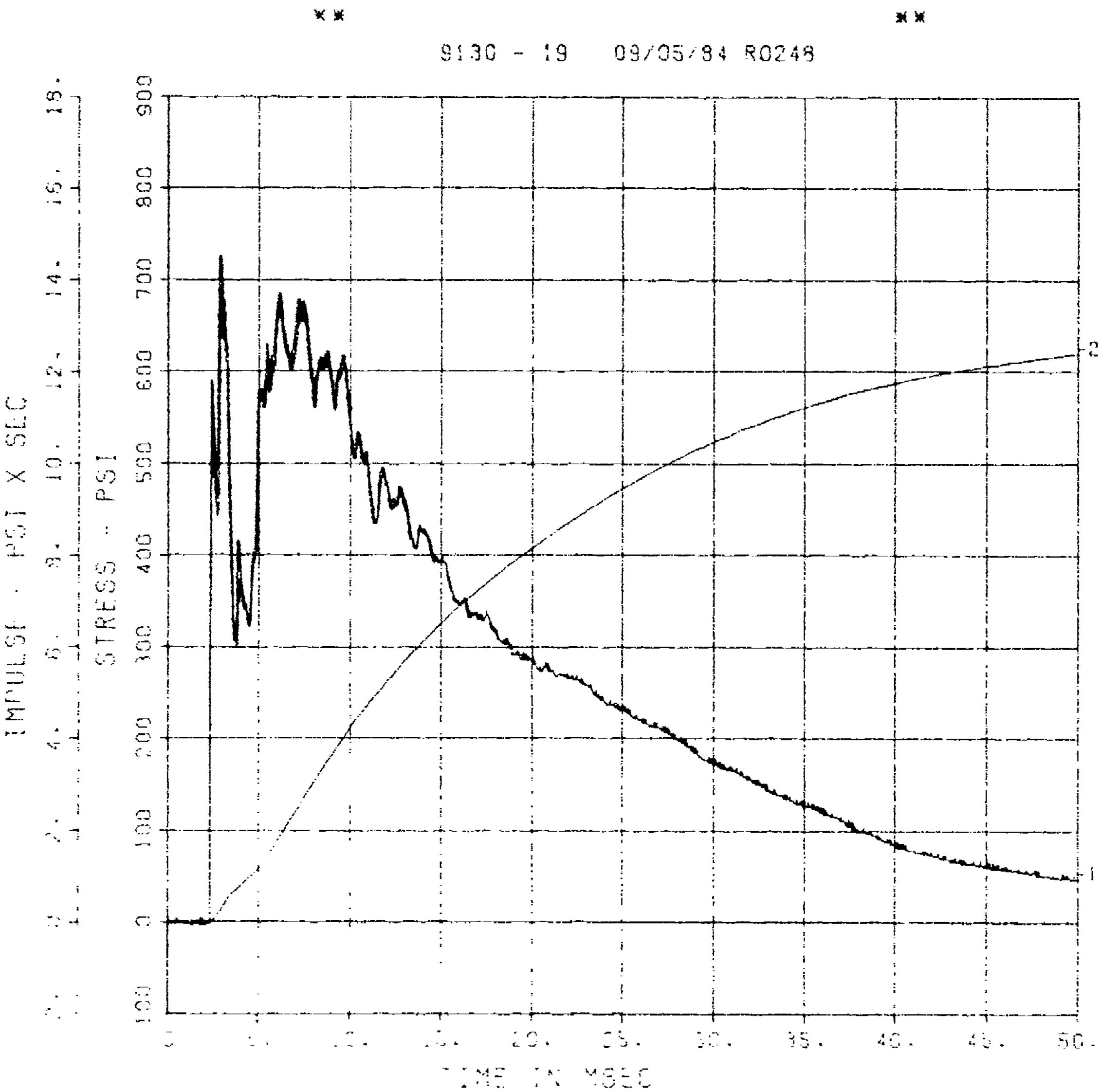

FEMA YIELD EFFECTS 1
IF-3
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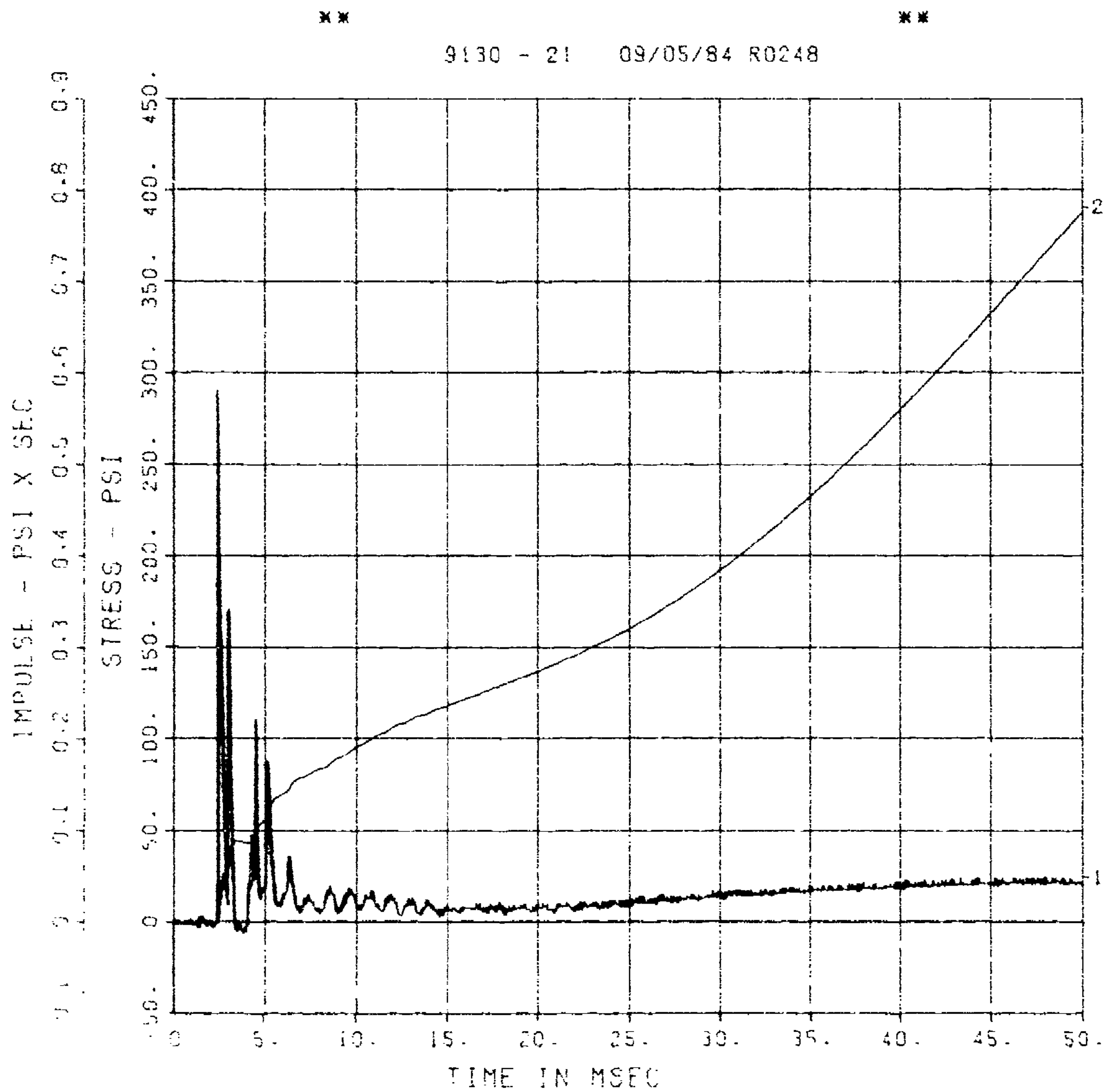

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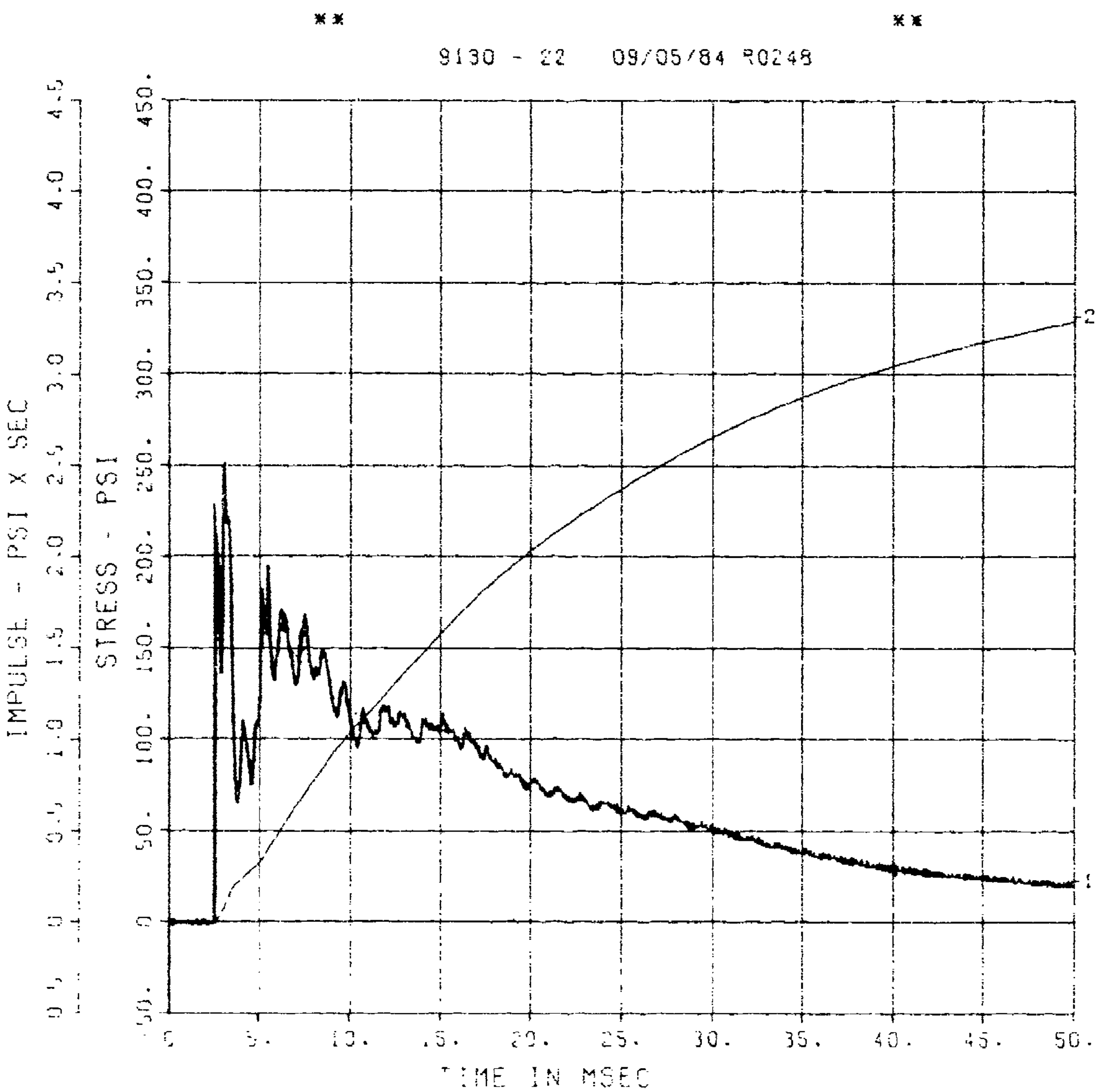

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IF-5
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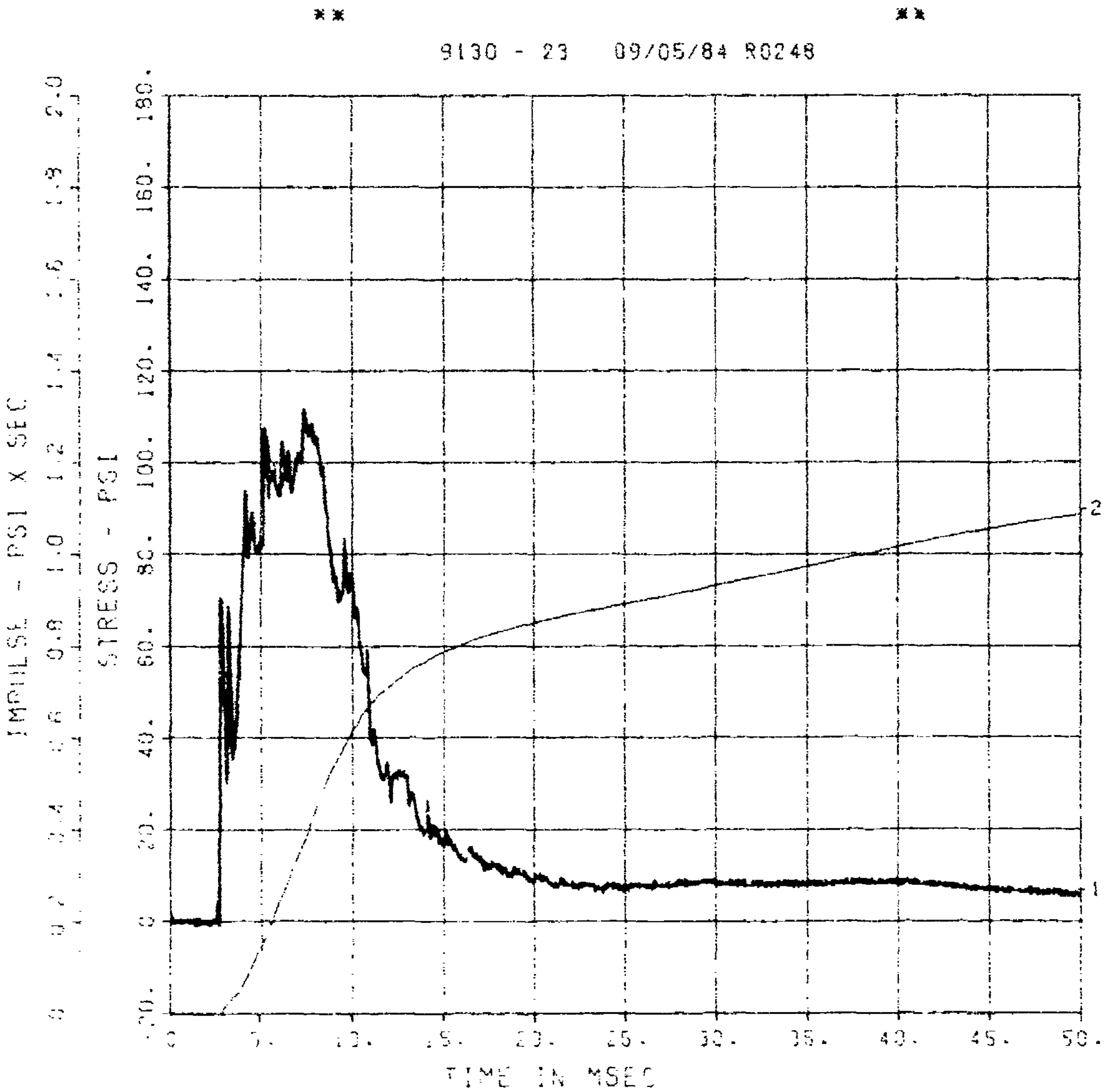

FEMA YIELD EFFECTS 1

EO-1

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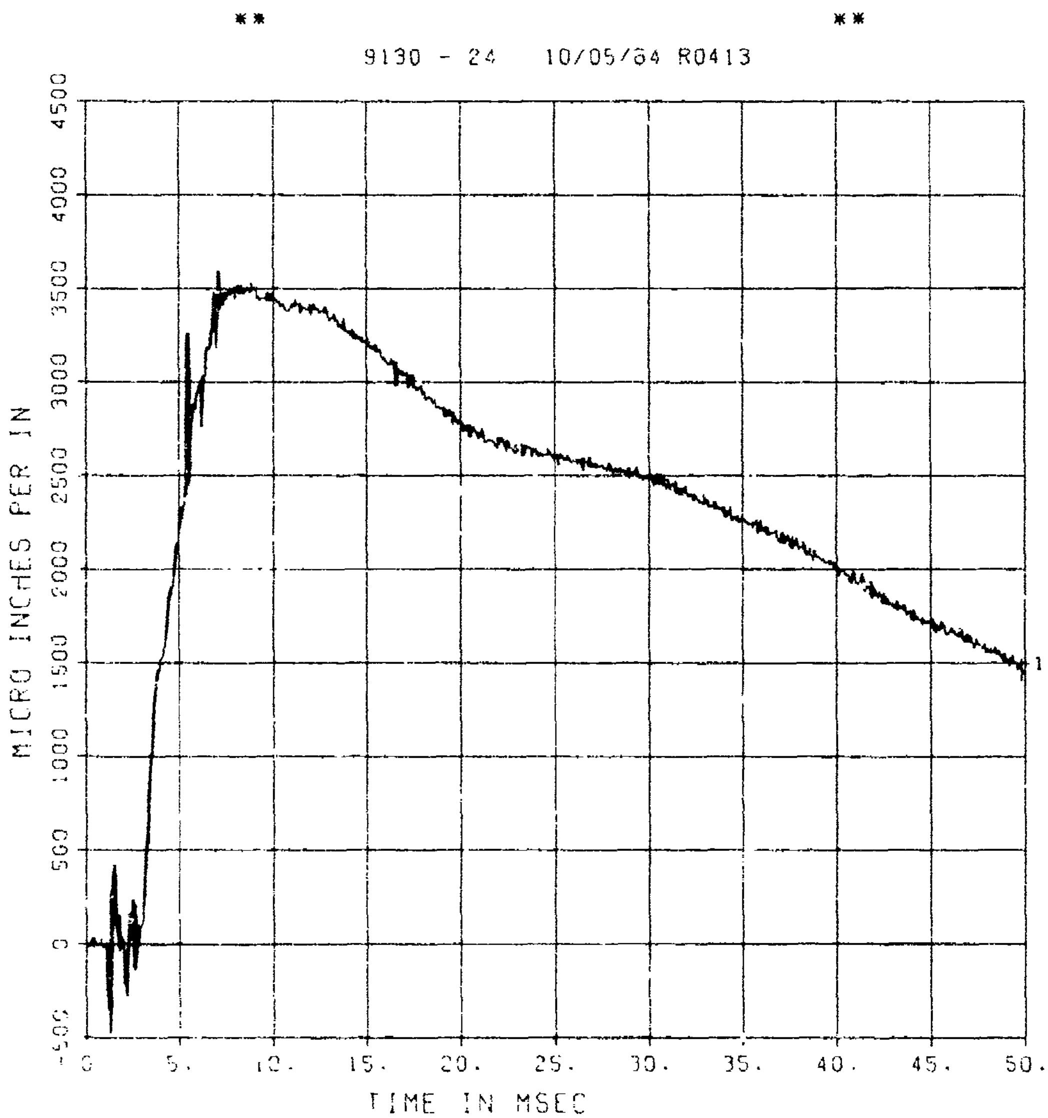
LP2/O 70% CUTOFF= 18000. HZ



FEMA YIELD EFFECTS 1

EO-1A

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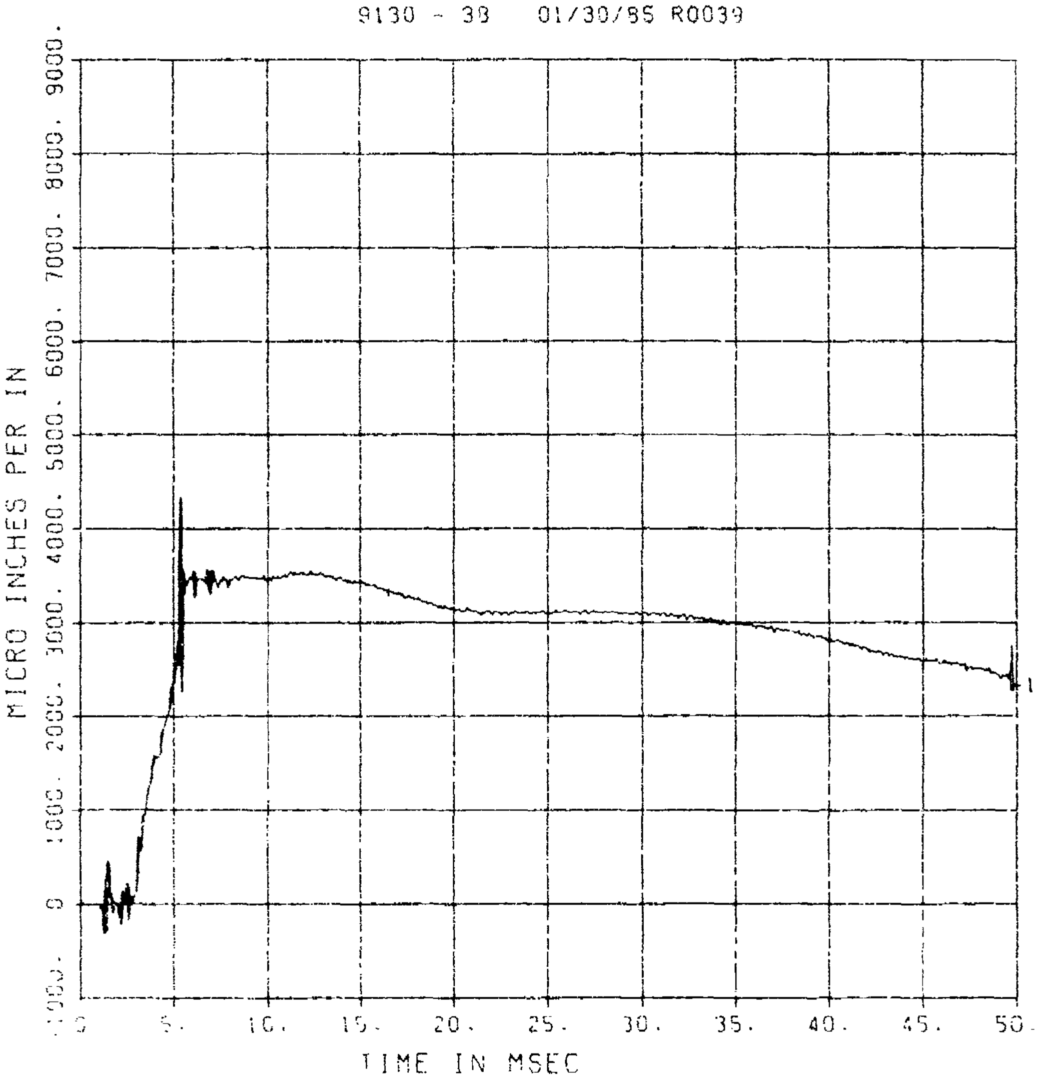

FEMA YIELD EFFECTS 1

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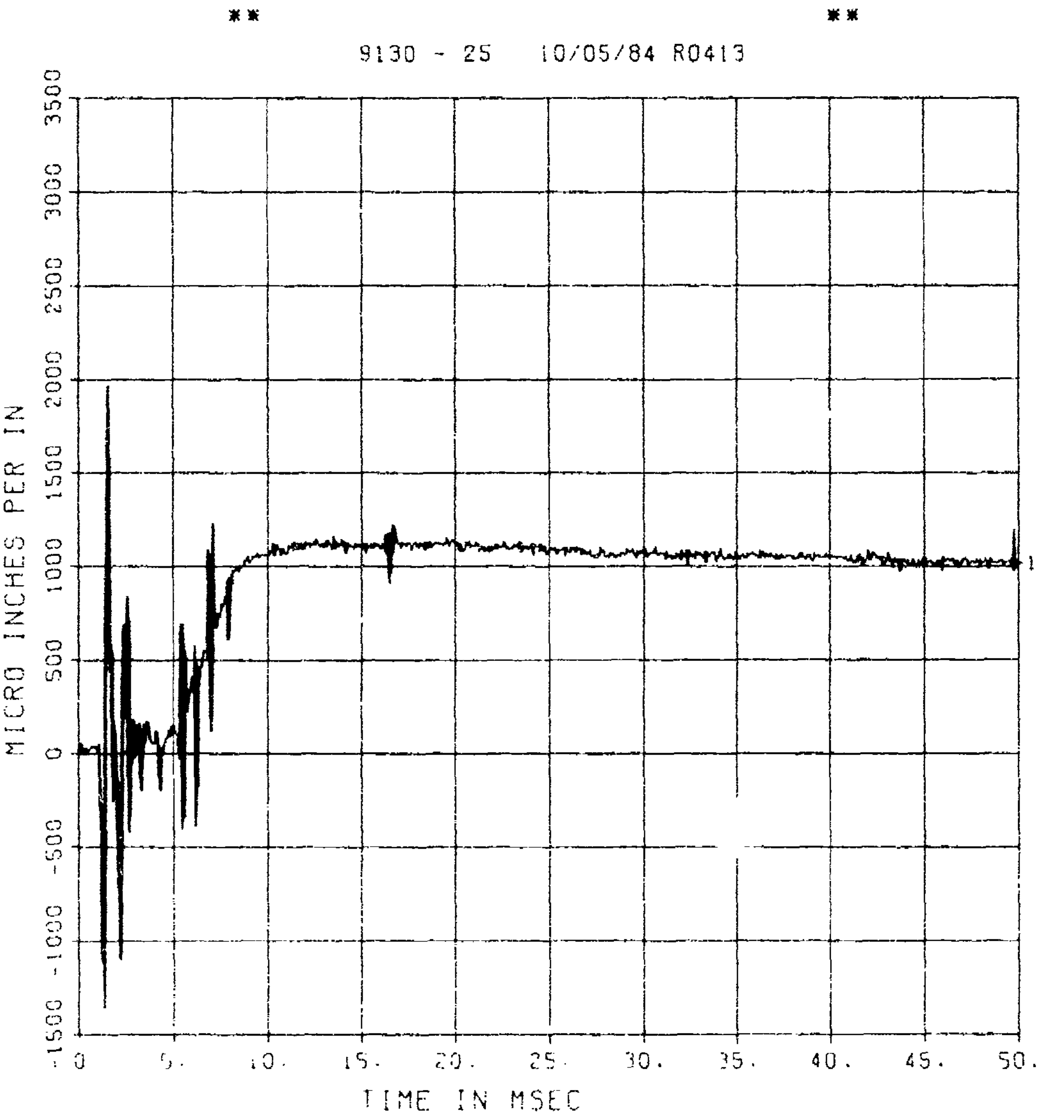

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E0-2
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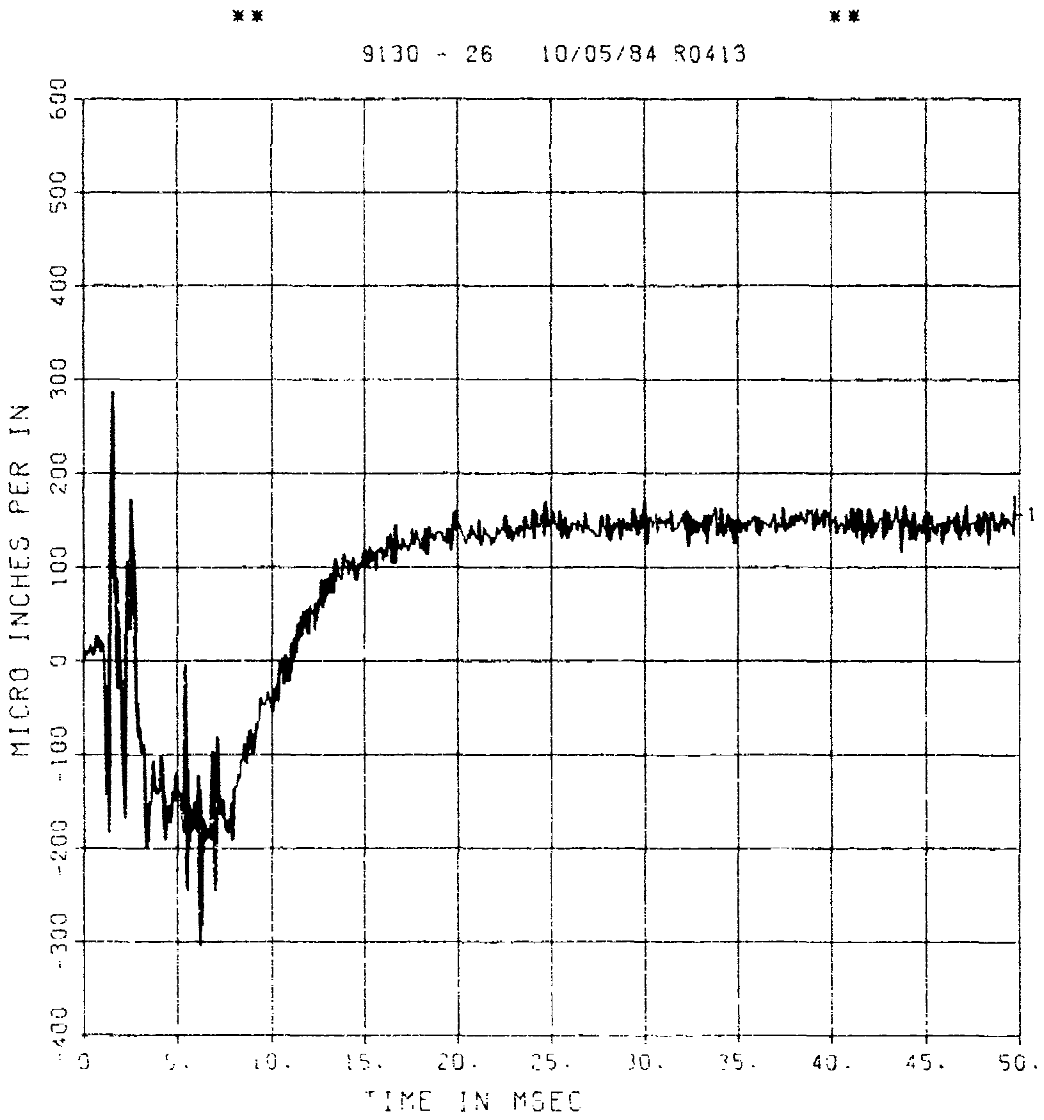

FEMA YIELD EFFECTS 1

E0-2A

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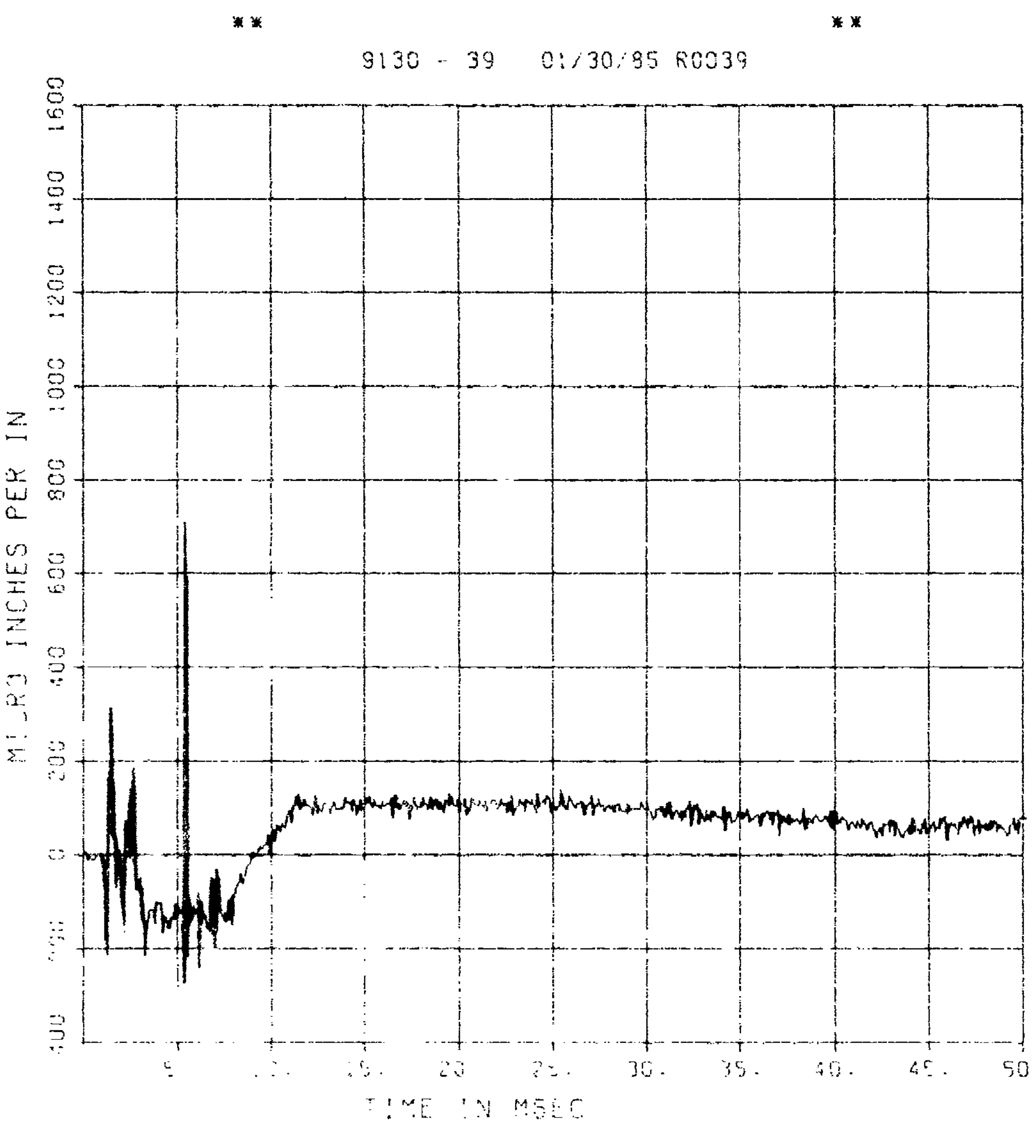

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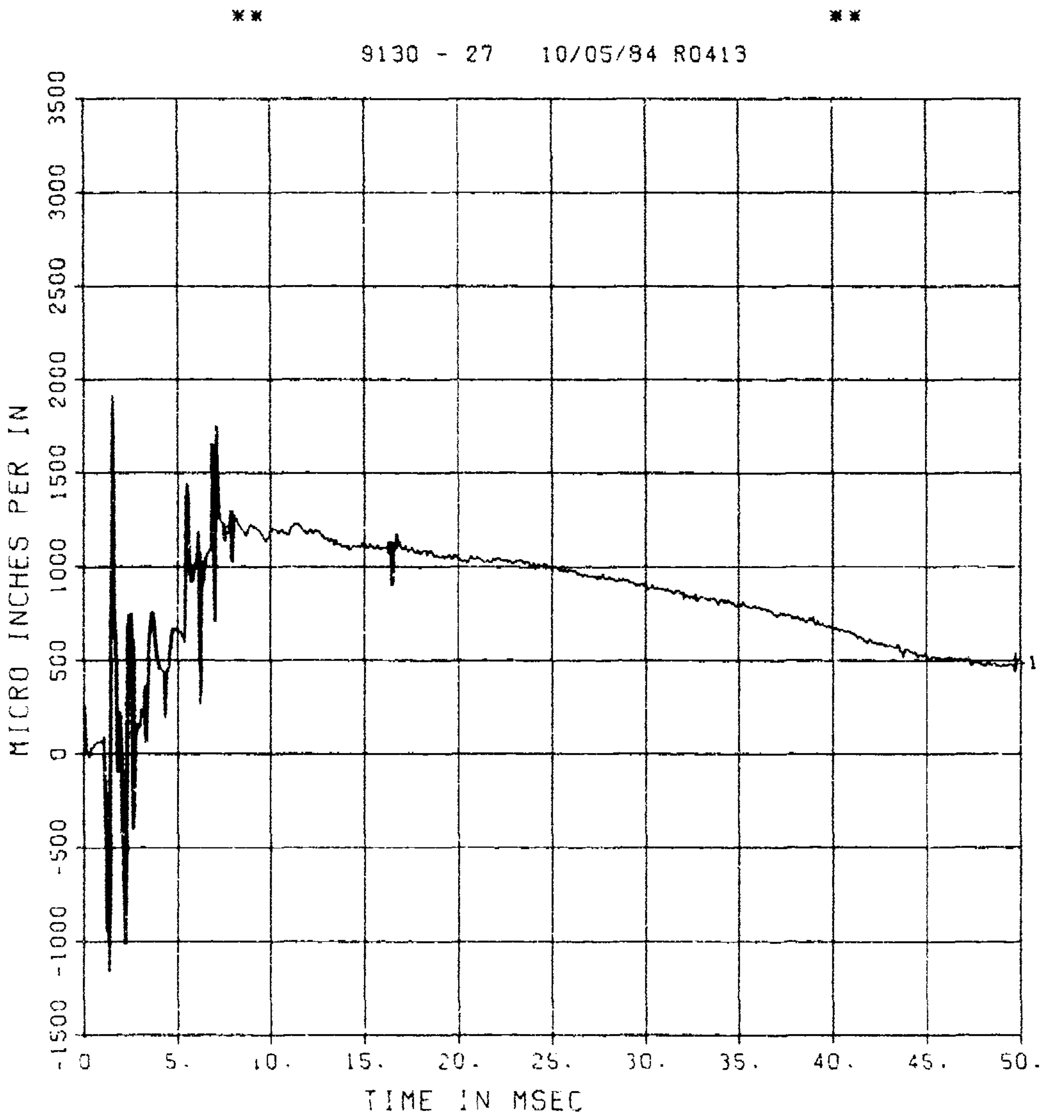

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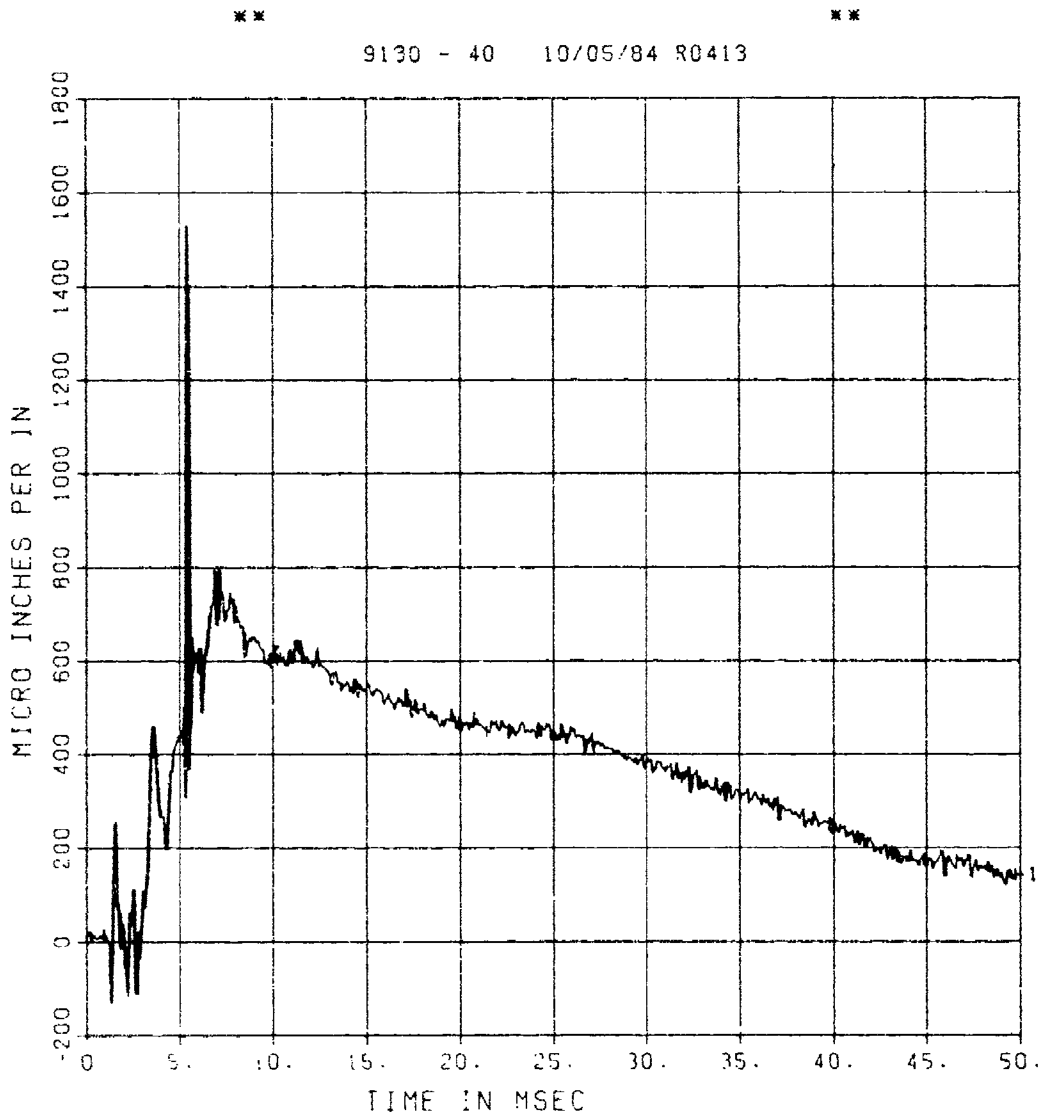

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EO-3A

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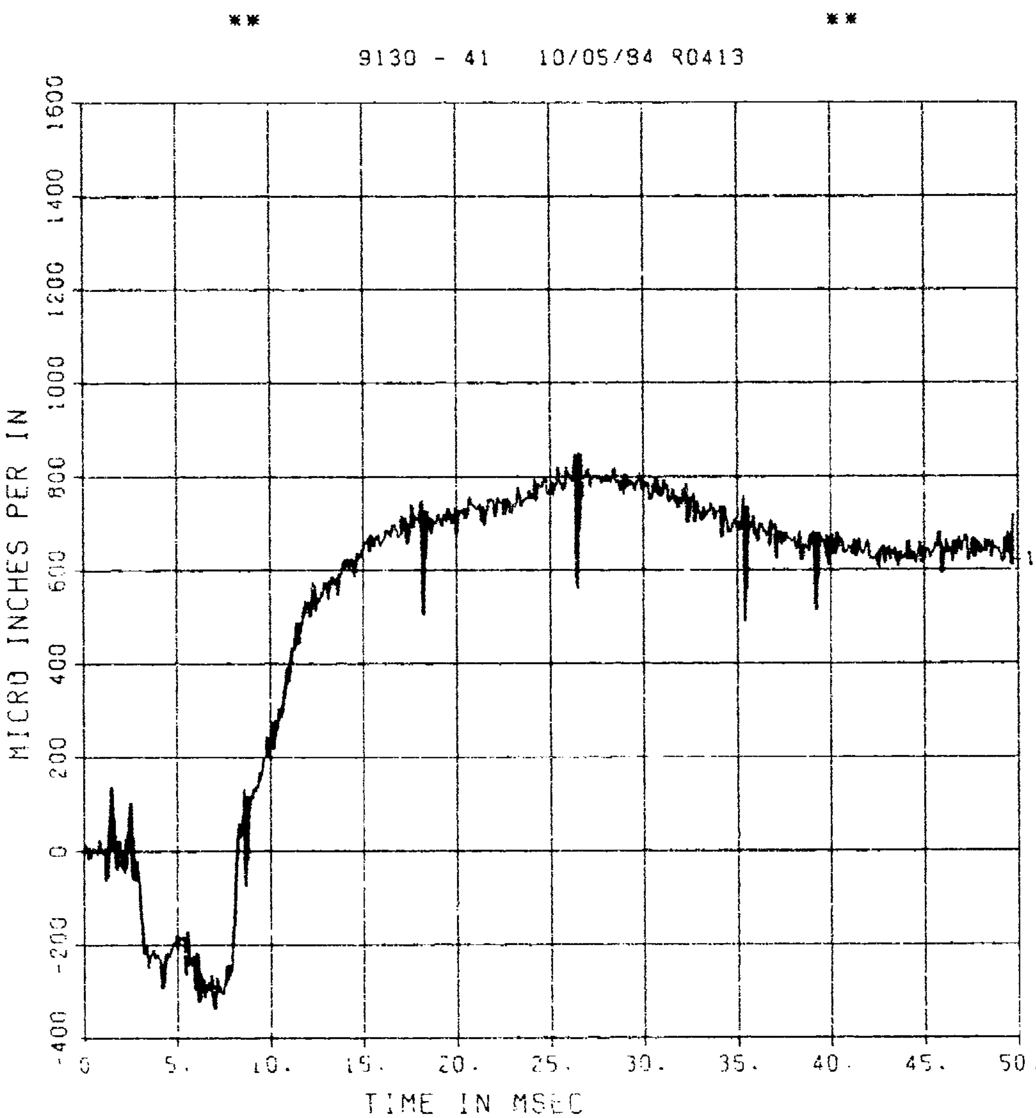

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EI-3
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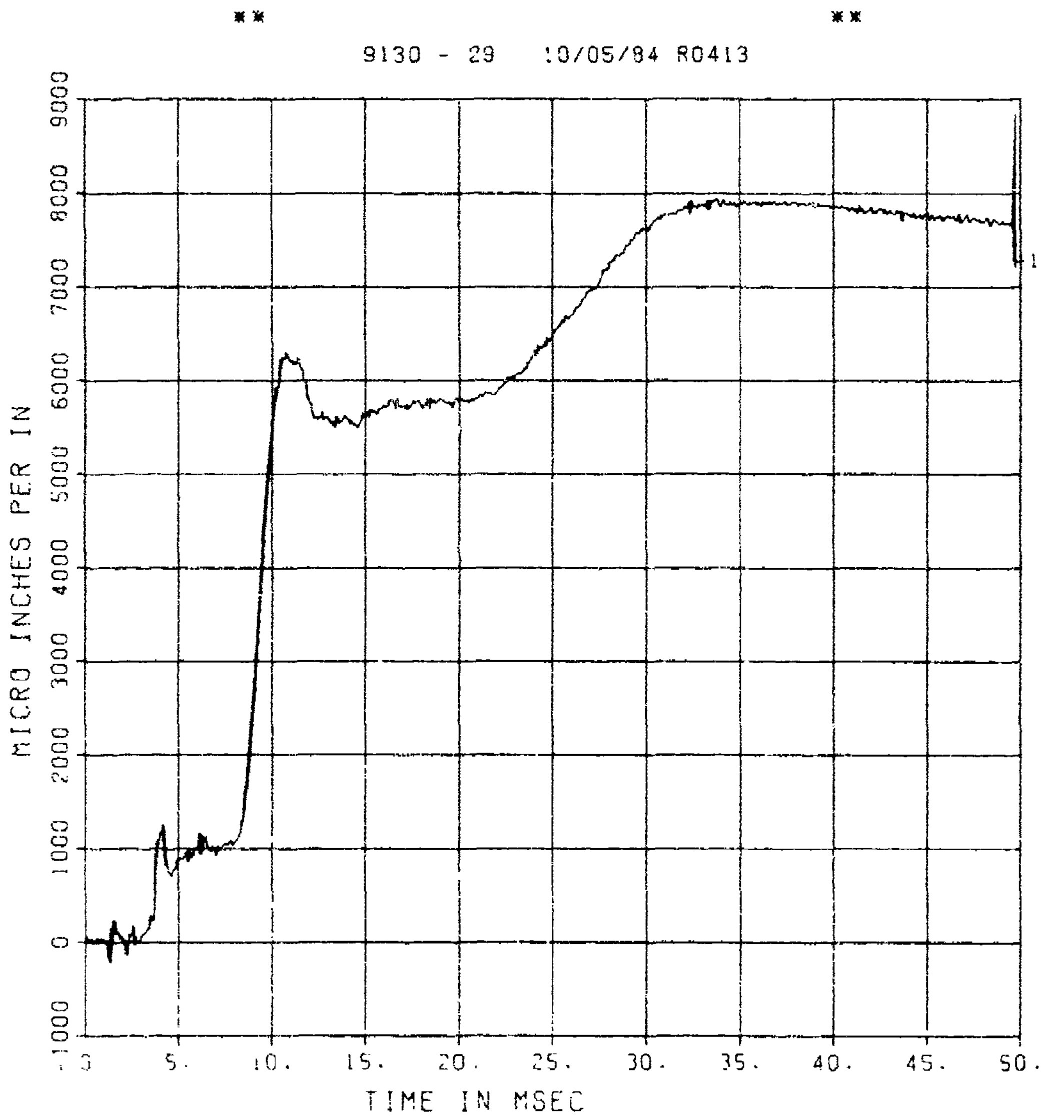
LP2/4 70% CUTOFF= 9000. HZ



FEMA YIELD EFFECTS 1

EI-3A

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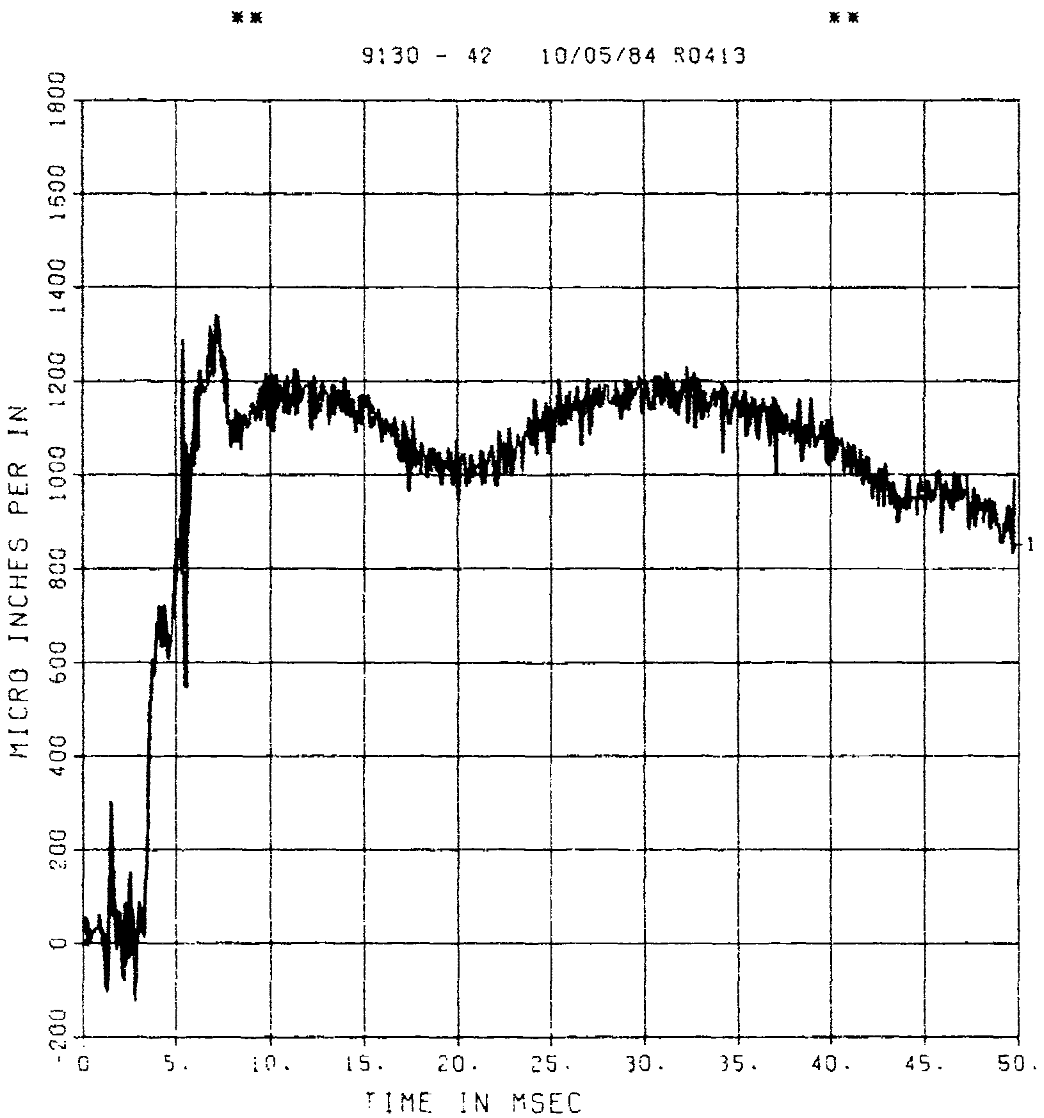
LP4/4 70% CUTOFF= 9000. HZ



FEMA YIELD EFFECTS 1

EO-4

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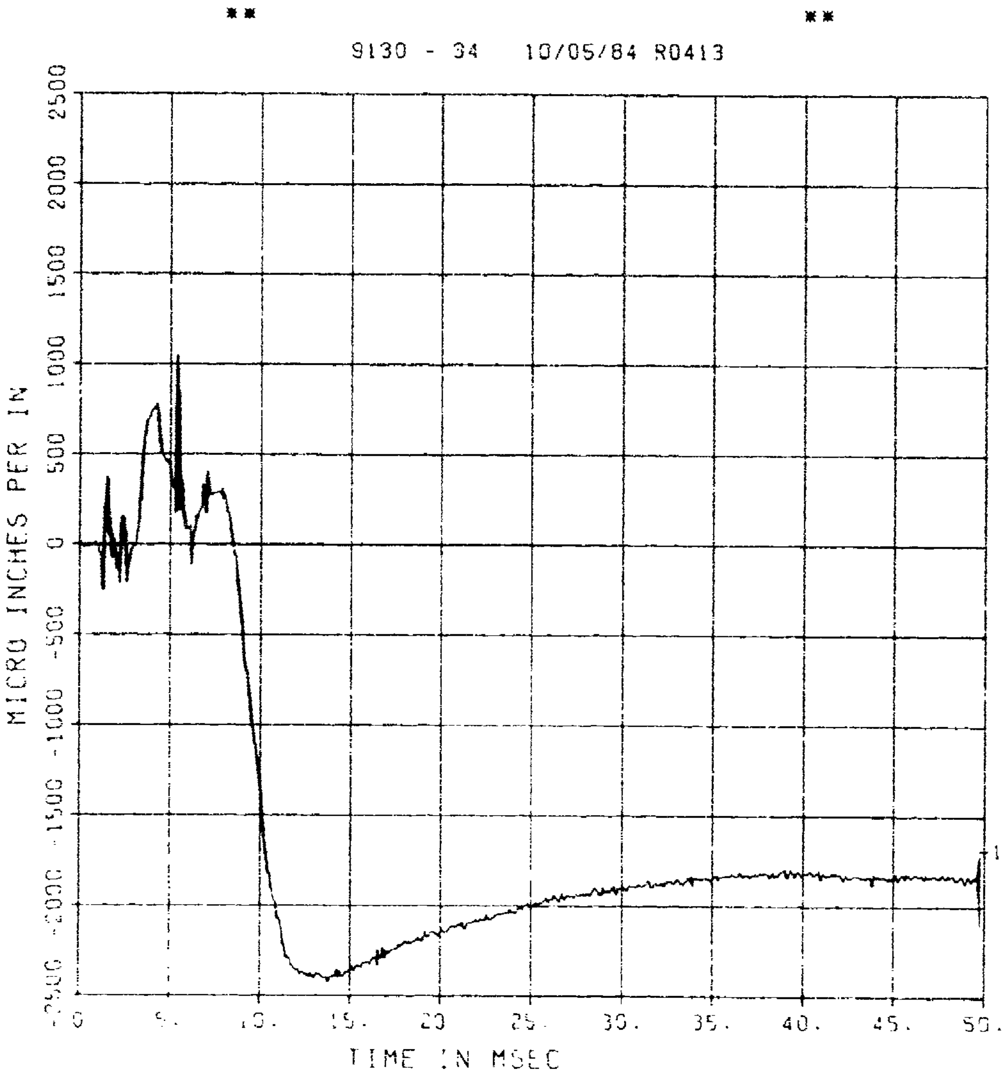
LP2/4 70% CUTOFF= 9000. HZ



FEMA YIELD EFFECTS 1

E0-4A

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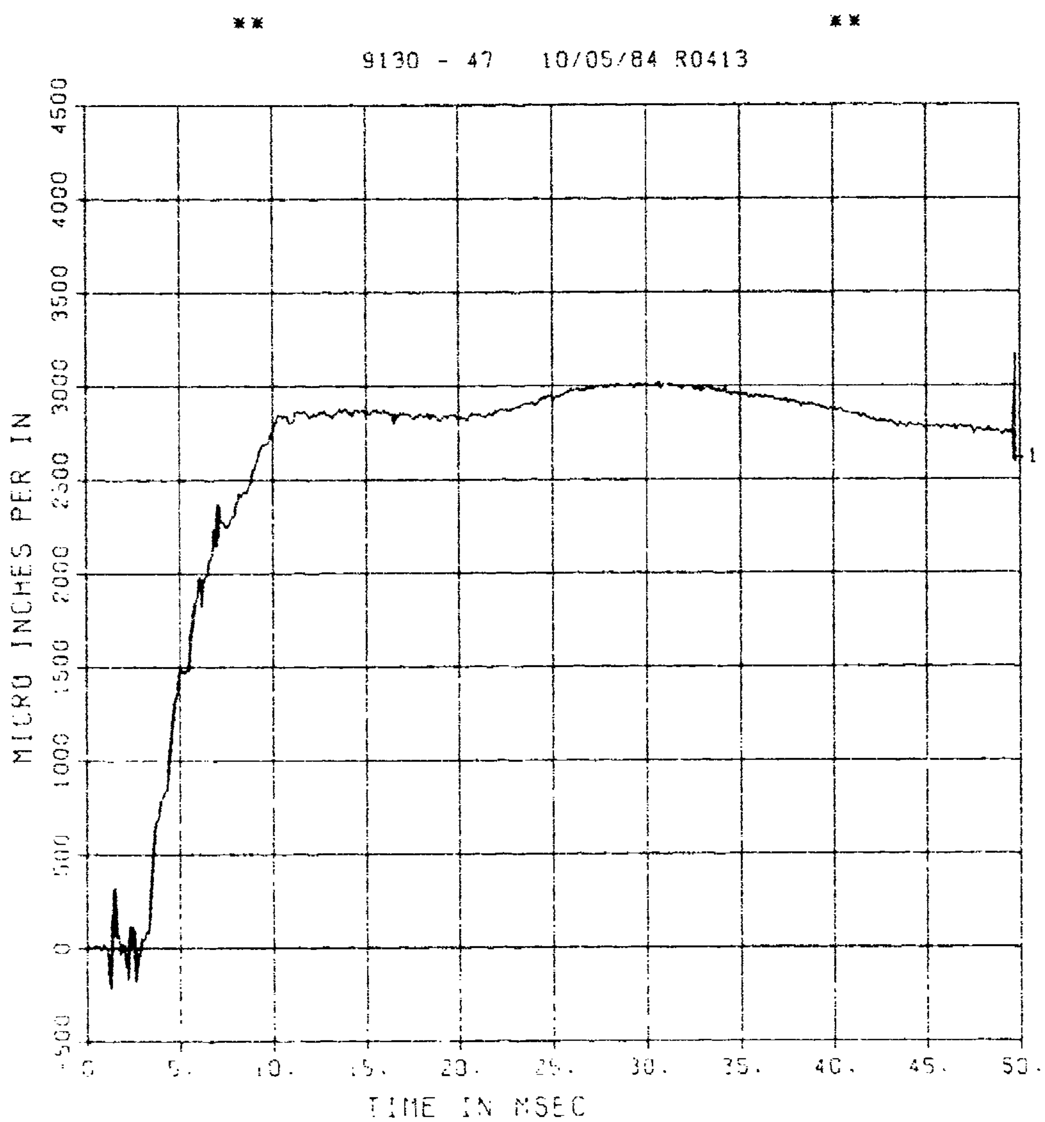

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EI-4
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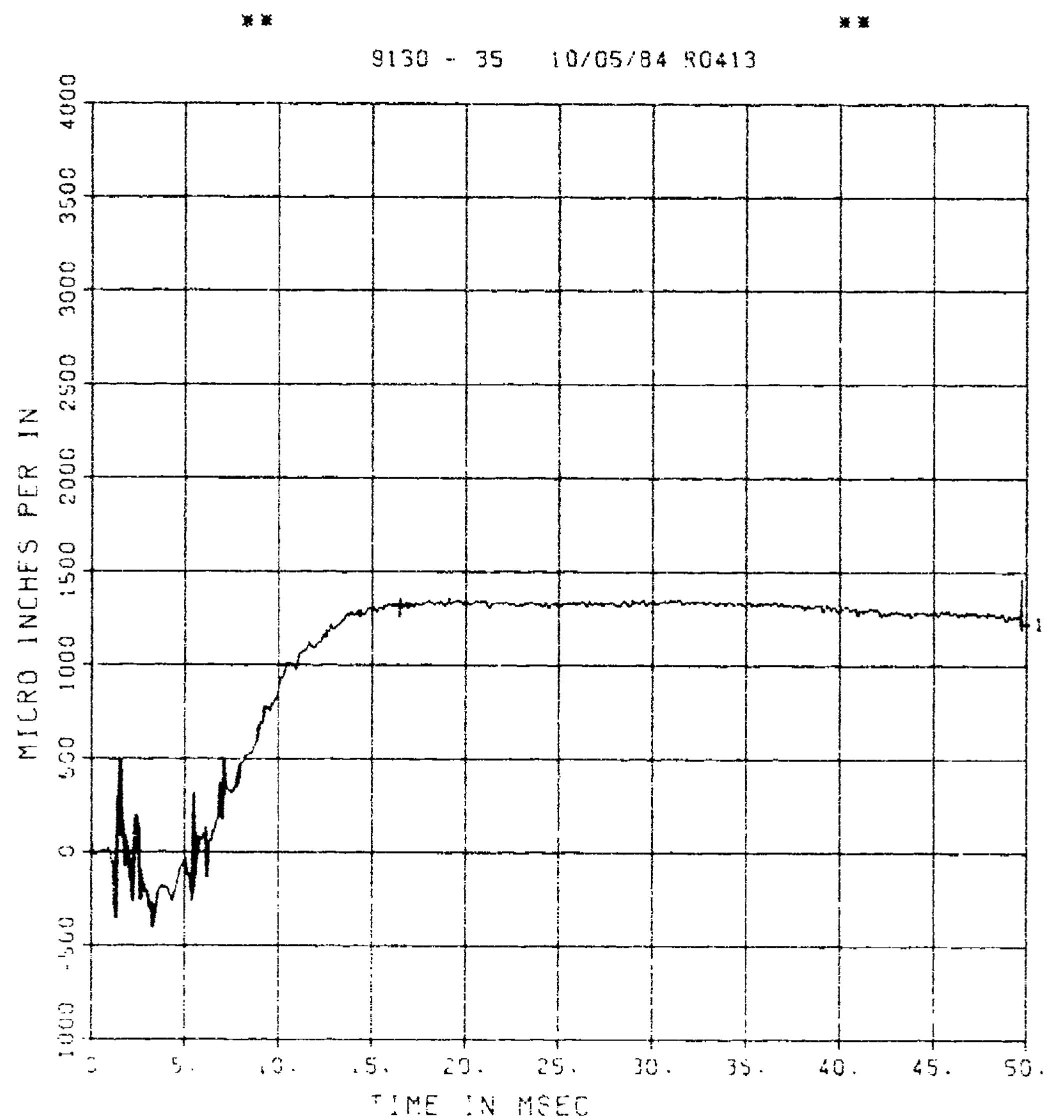
LP2/4 70% CUTOFF= 9000. HZ



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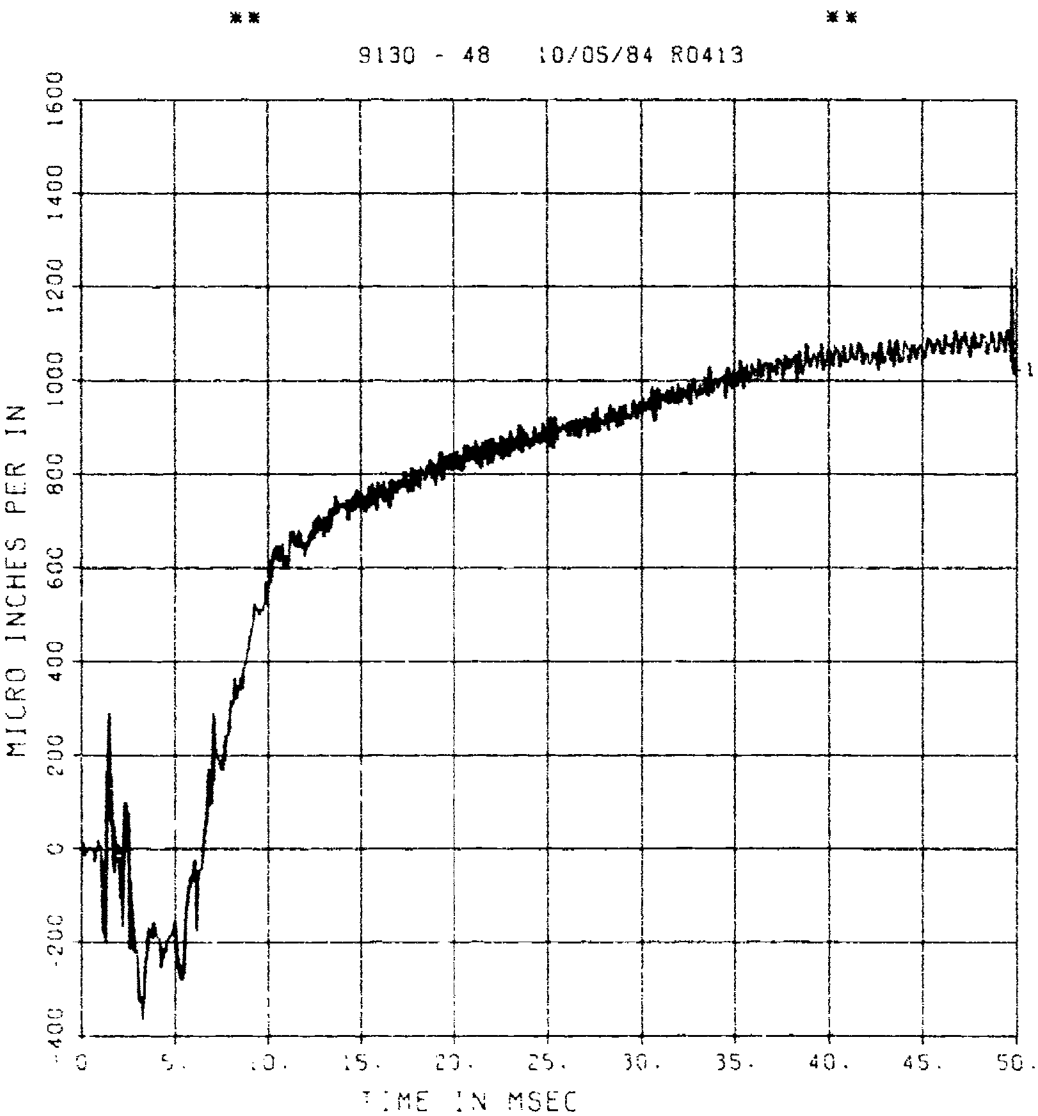
LF4/0 70% CUTOFF= 9000. HZ



FEMA YIELD EFFECTS 1

E-5

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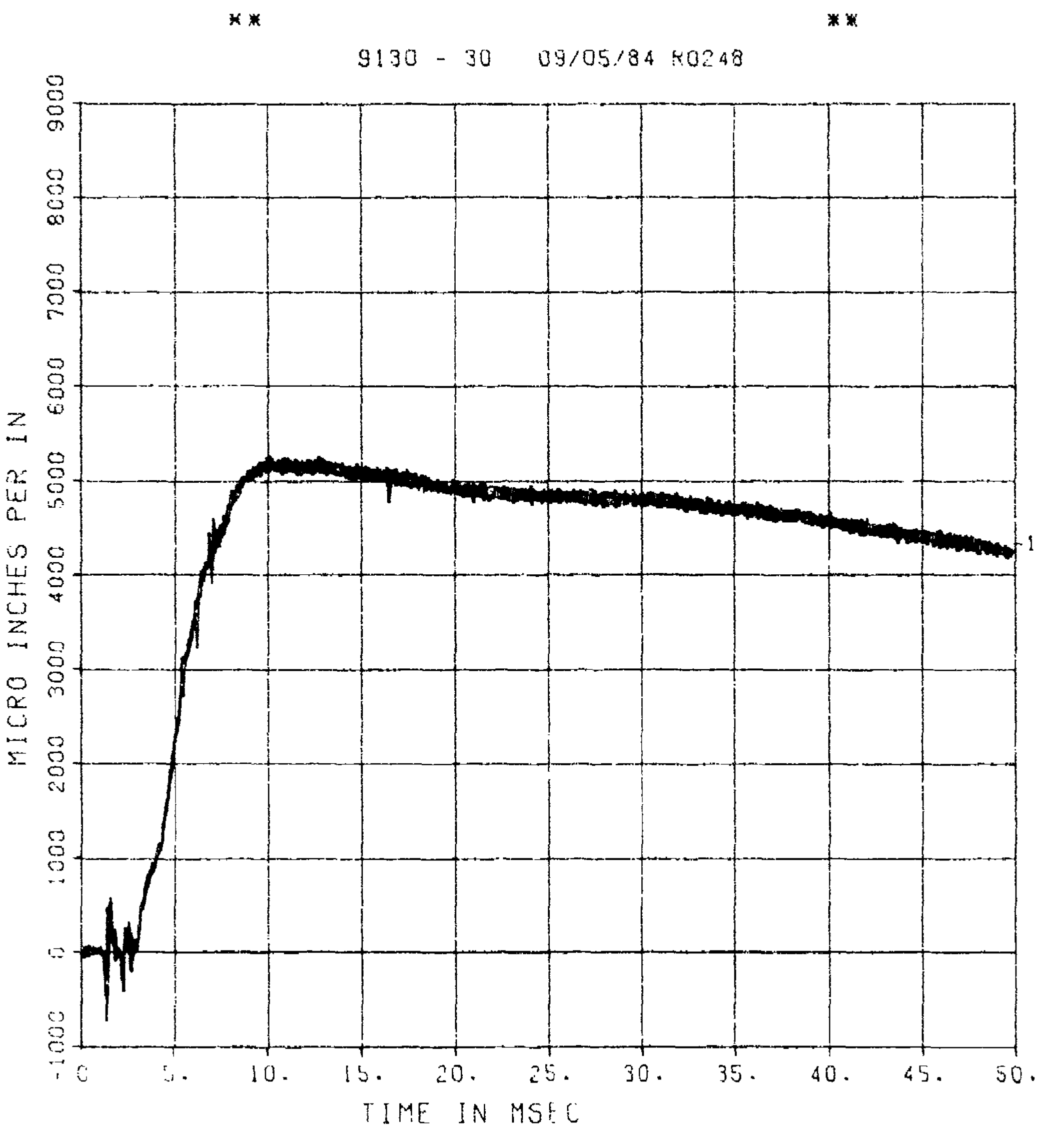

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E-5A
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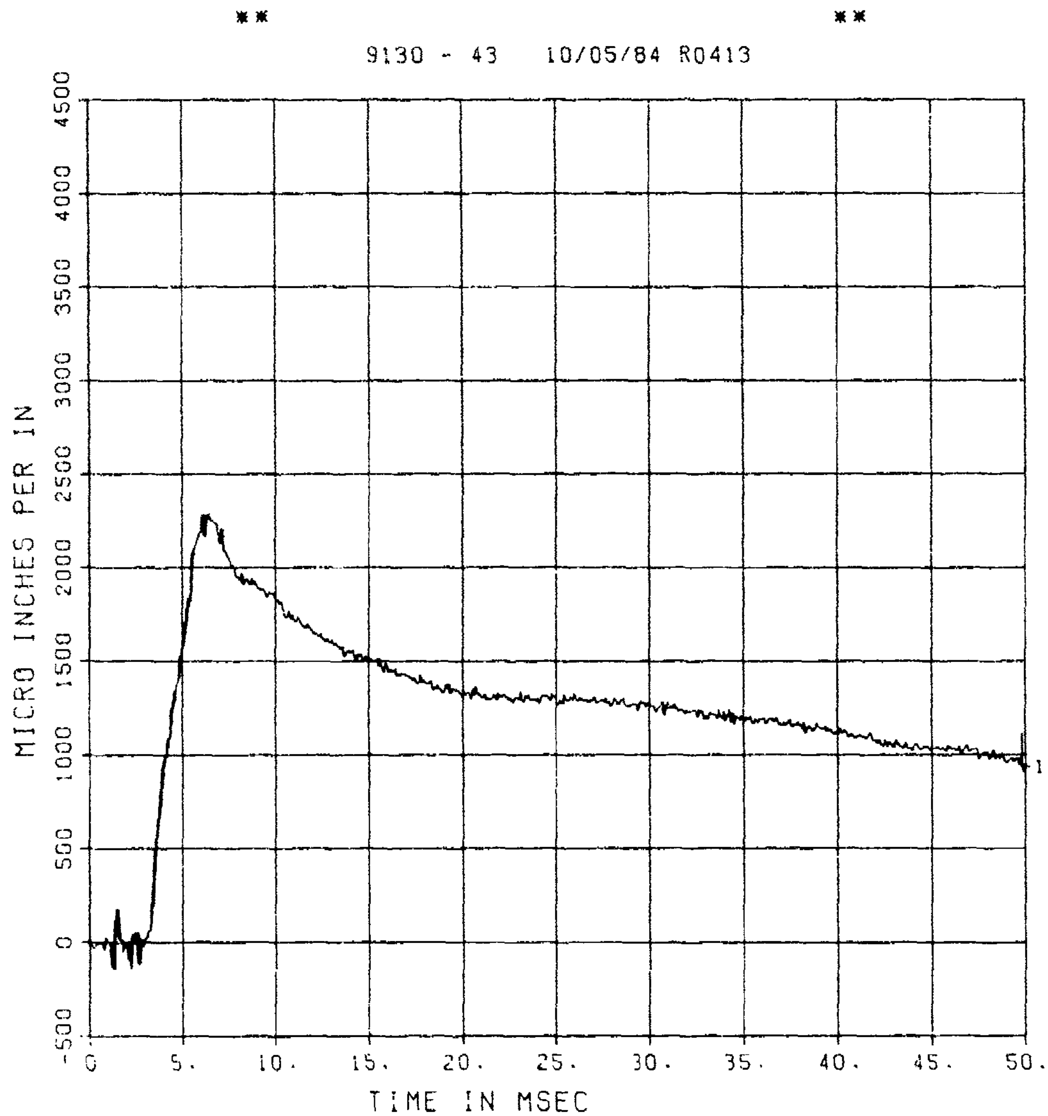
LP4/0 70% CUTOFF= 9000. HZ



FEMA YIELD EFFECTS 1

E-6

200000. HZ CAL= 19670.

LP4/0 70% CUTOFF= 9000. HZ

** **

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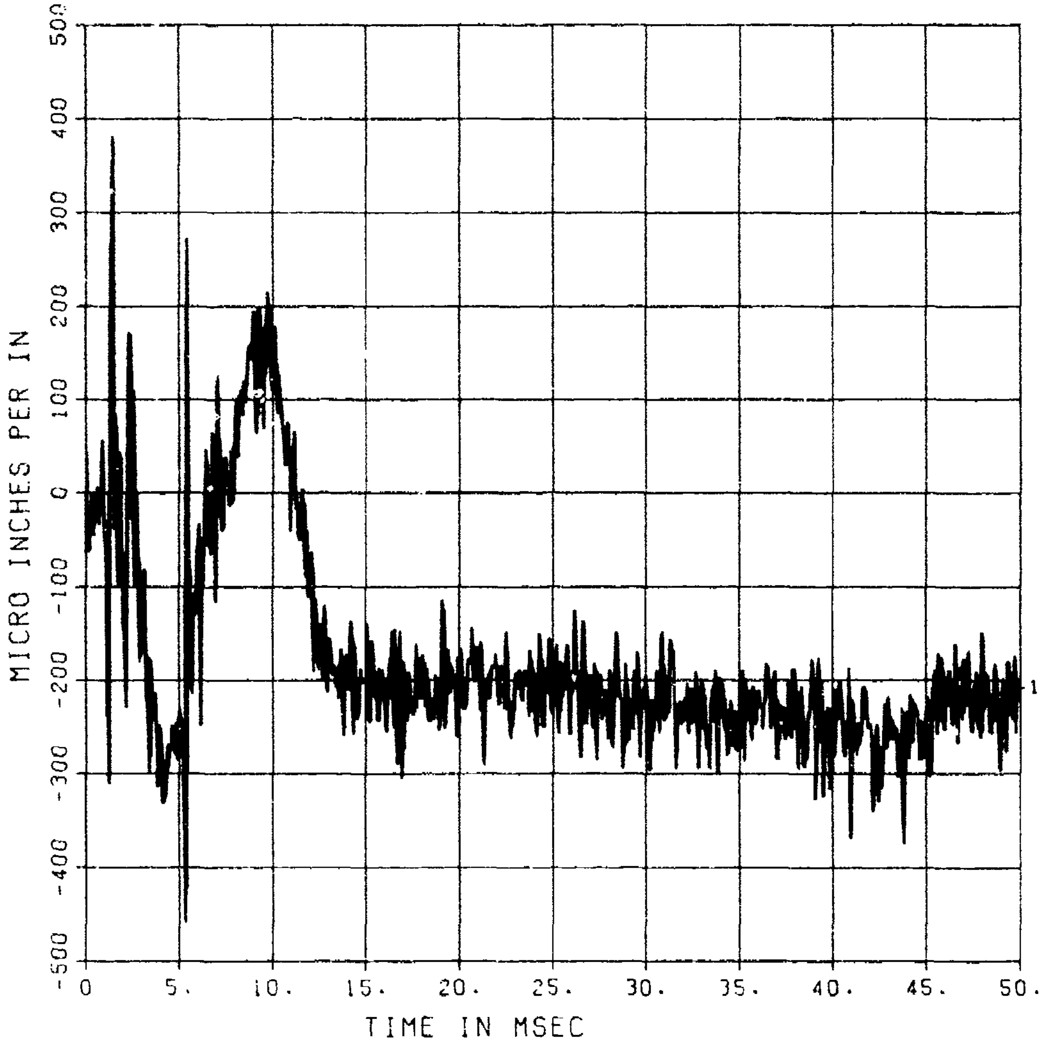

FEMA YIELD EFFECTS 1

E-6A

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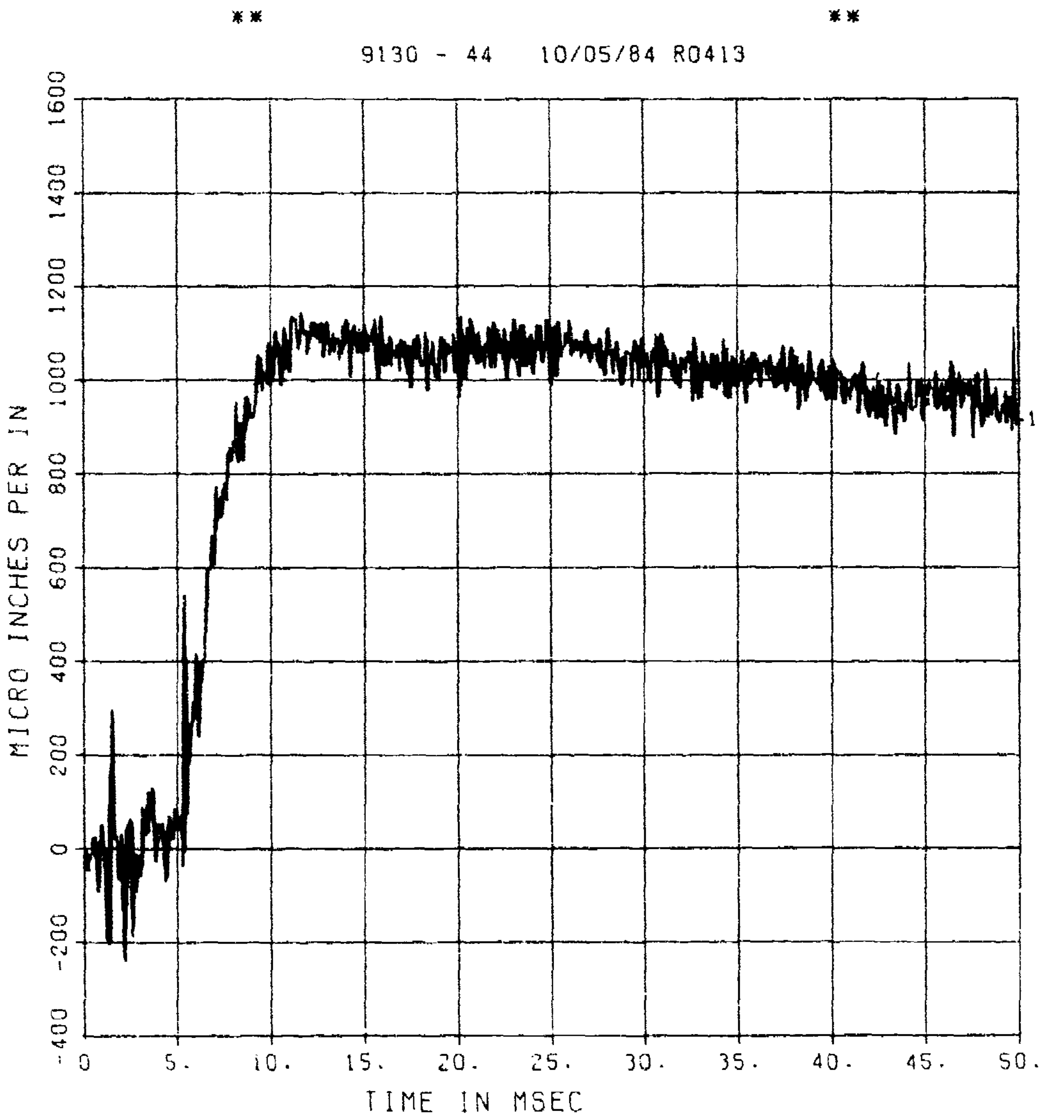
LP4/0 70% CUTOFF= 9000. HZ



FEMA YIELD EFFECTS 1

E--7

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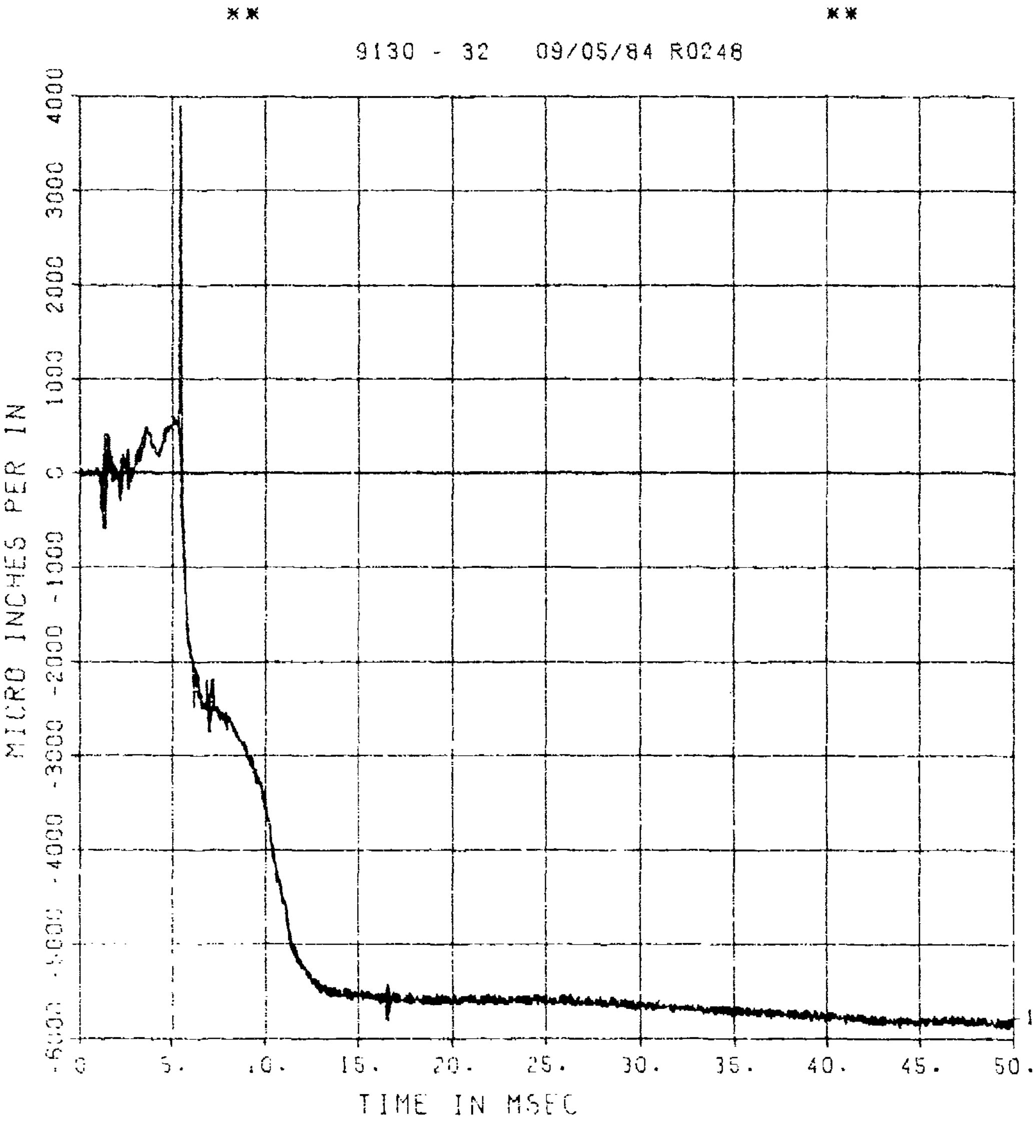

FEMA YIELD EFFECTS 1
E-7A
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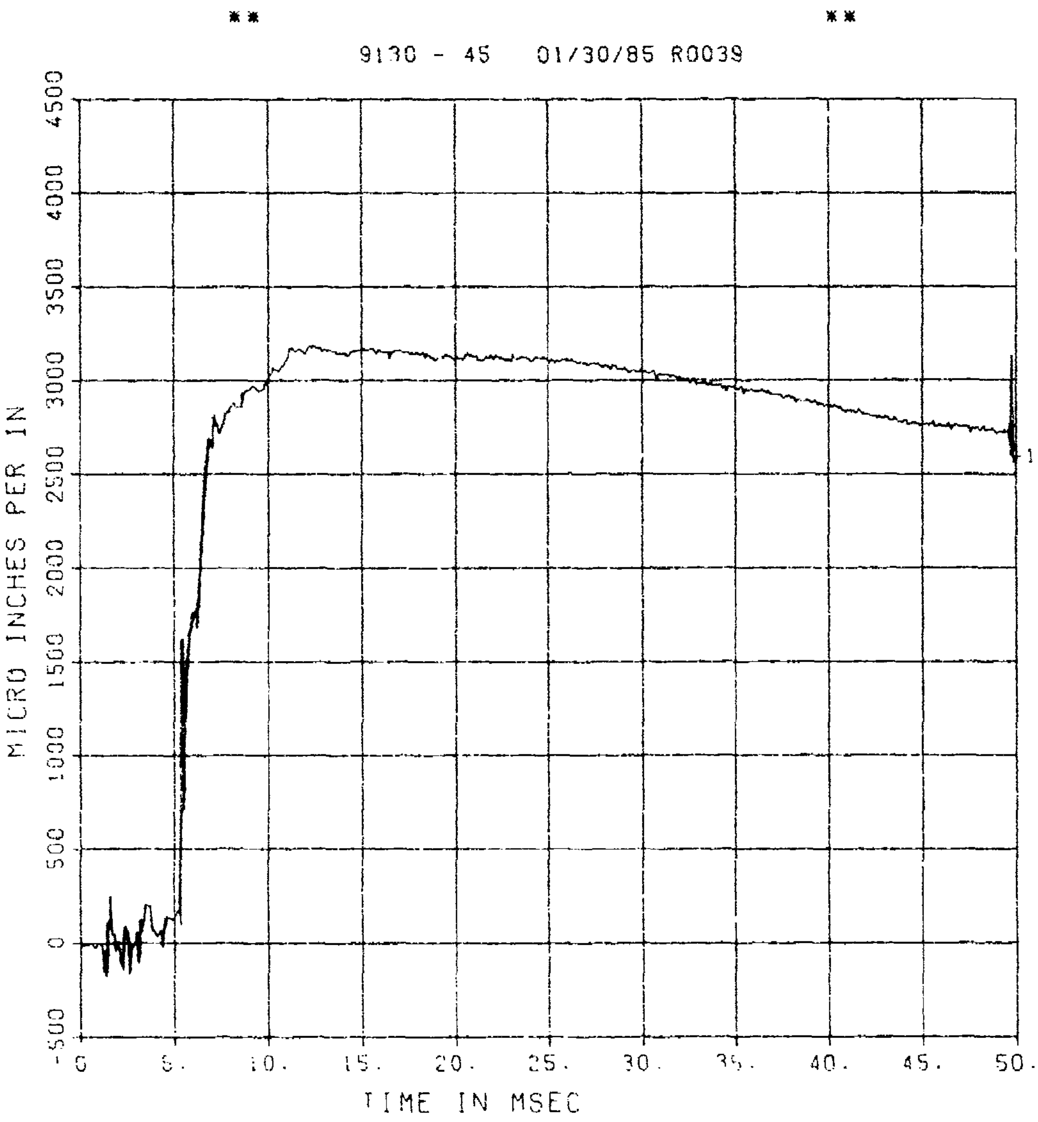

FEMA YIELD EFFECTS 1
E-8
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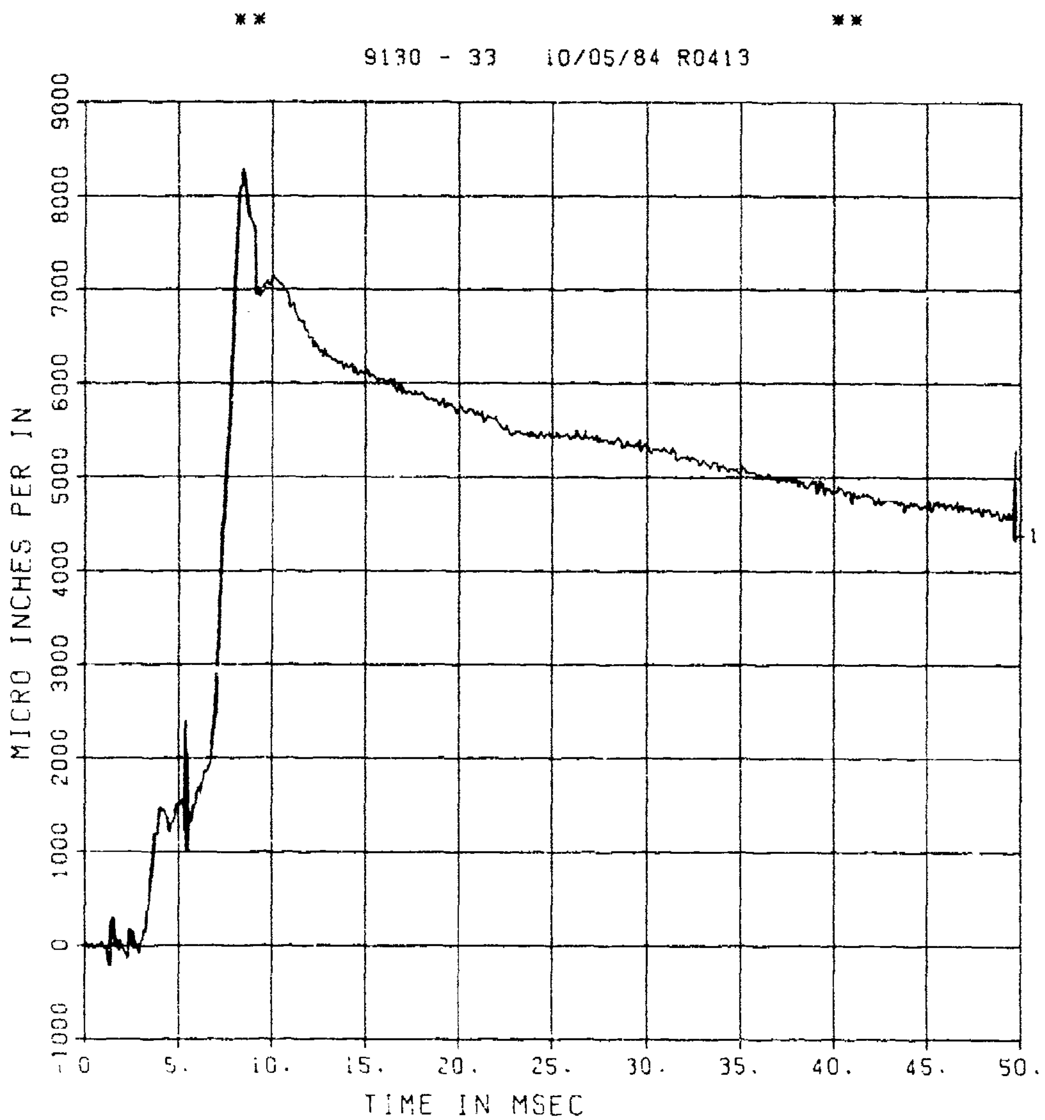
LP2/4 70% CUTOFF= 9000. HZ



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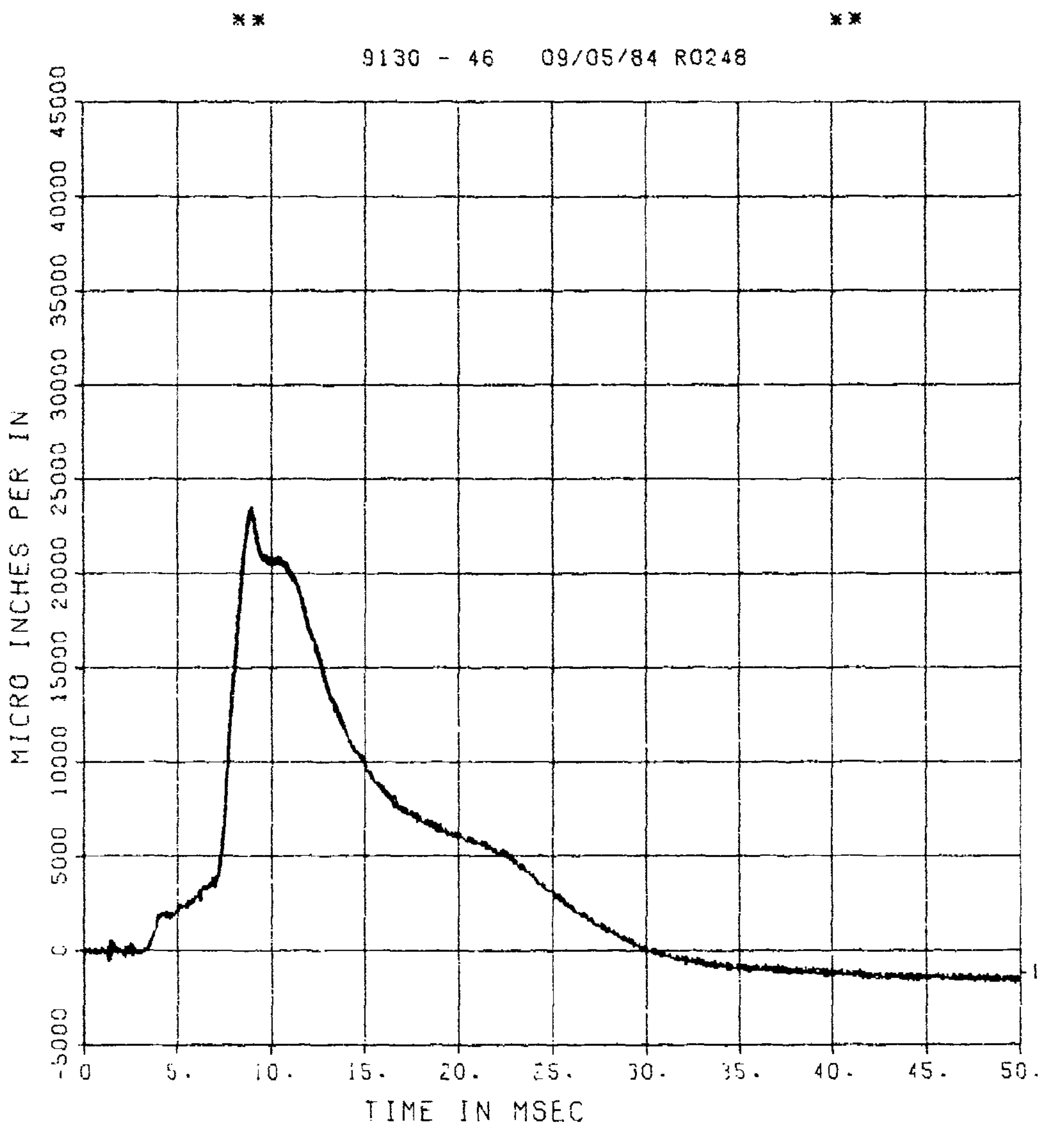

FEMA YIELD EFFECTS 1

D-1

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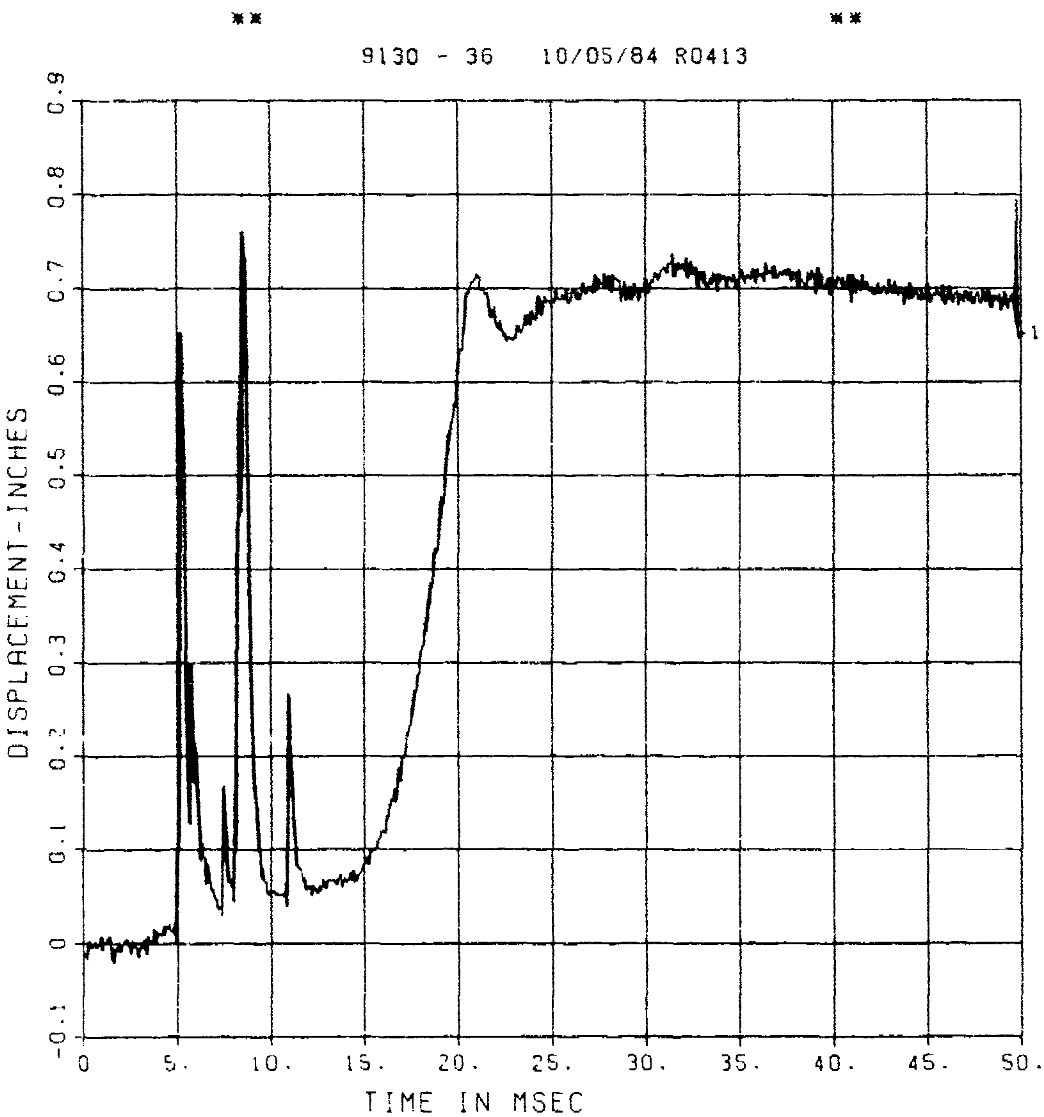
LP4/0 70% CUTOFF= 9000. HZ



FEMA YIELD EFFECTS 2
BP-1
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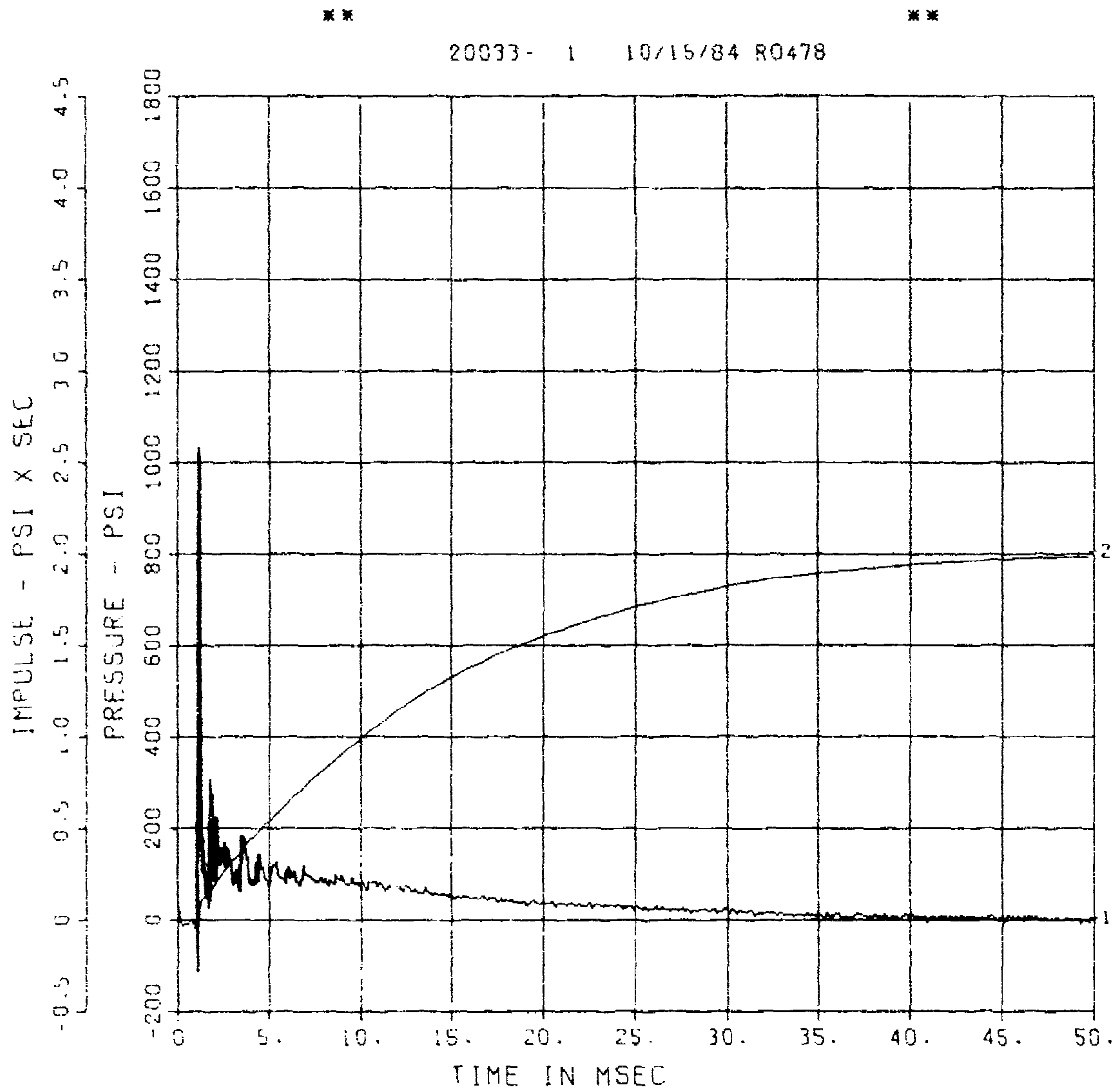
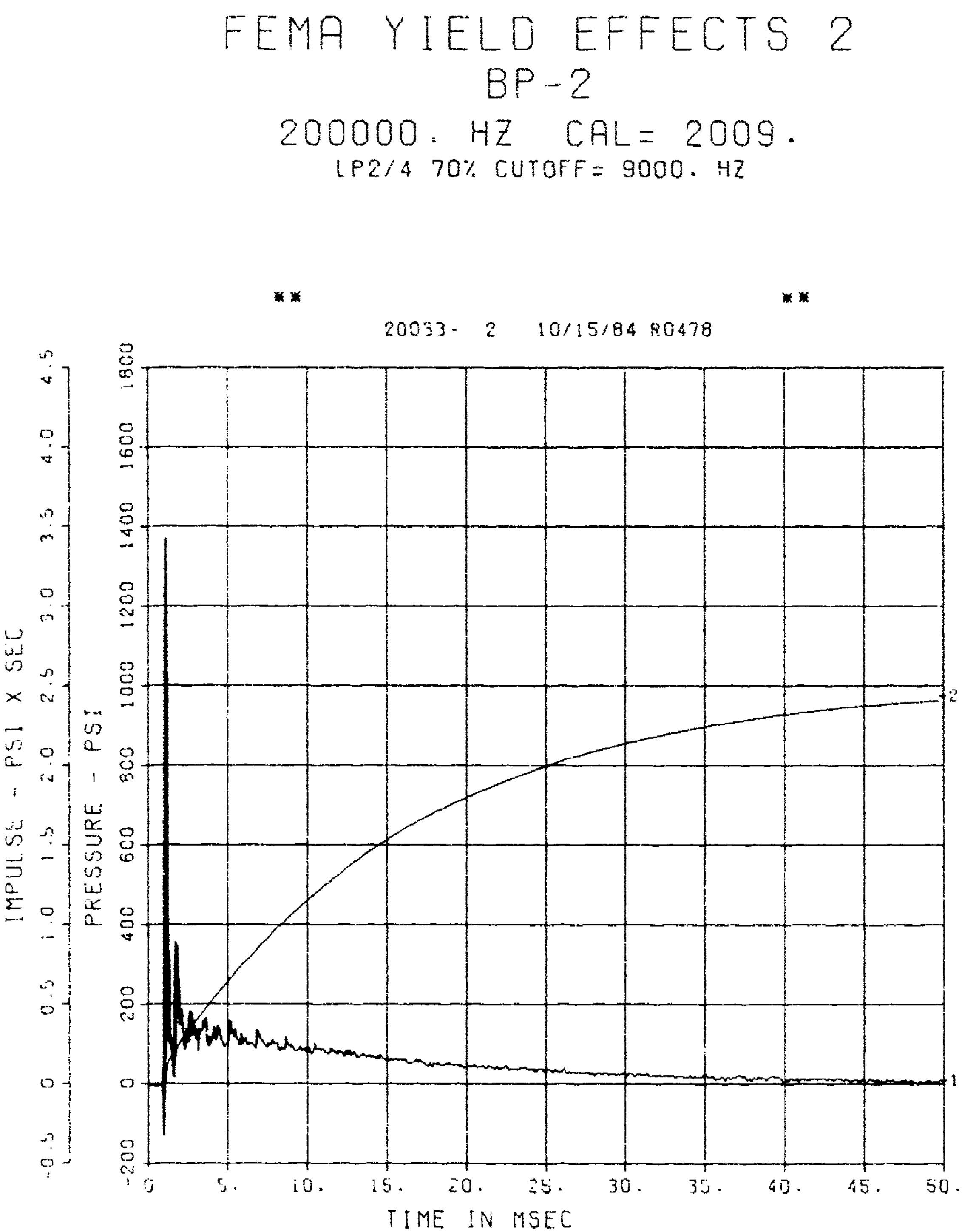


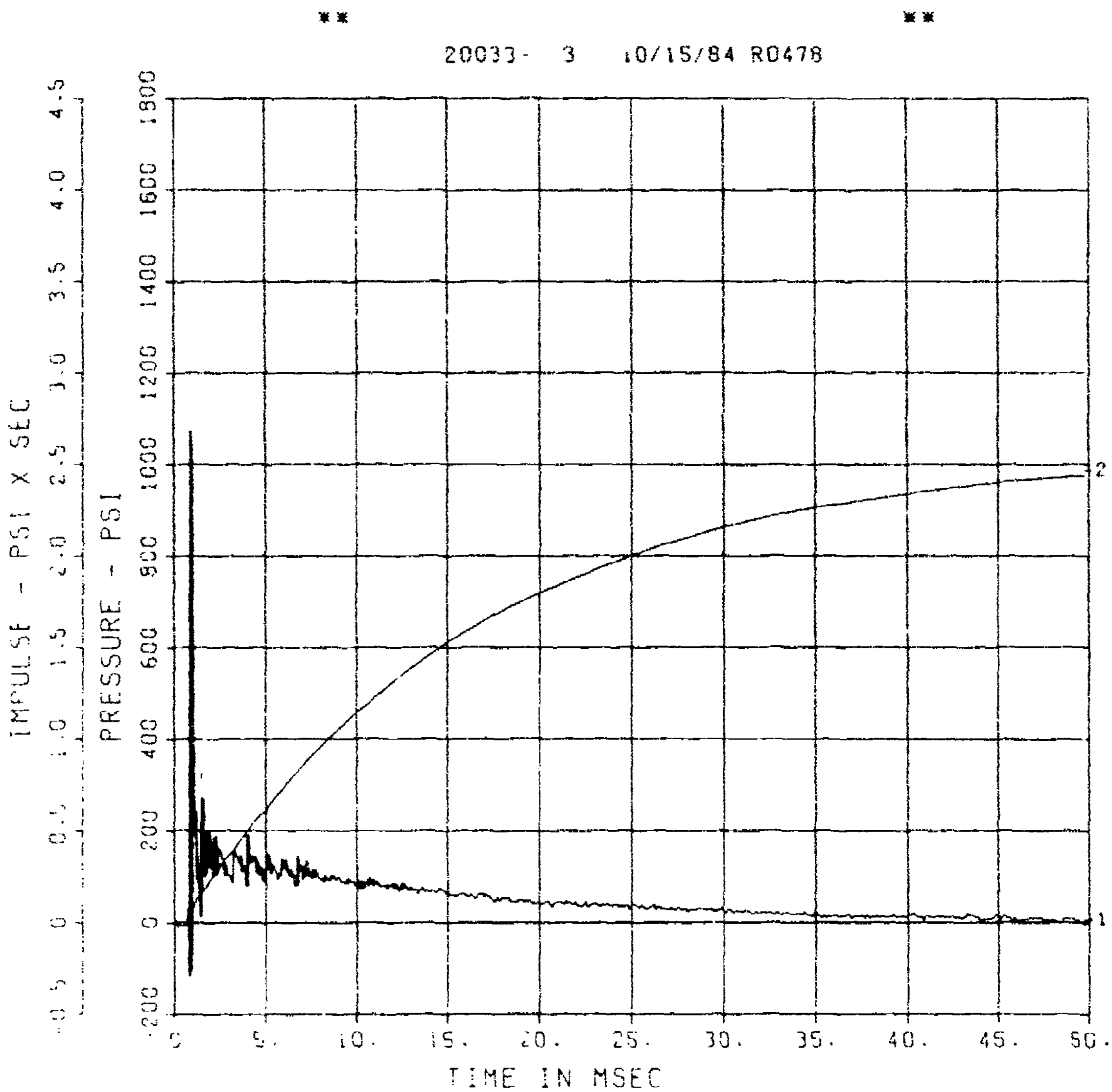

FEMA YIELD EFFECTS 2
BP-2
200000. HZ CAL= 2009.
LP2/4 70% CUTOFF= 9000. HZ
**
**
20033- 2 10/15/84 R0478
IMPULSE - PSI X SEC
PRESSURE - PSI
TIME IN MSEC
-0.5
0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
-200
0
200
400
600
800
1000
1200
1400
1600
1800
0
5.
10.
15.
20.
25.
30.
35.
40.
45.
50.
1
2

FEMA YIELD EFFECTS 2

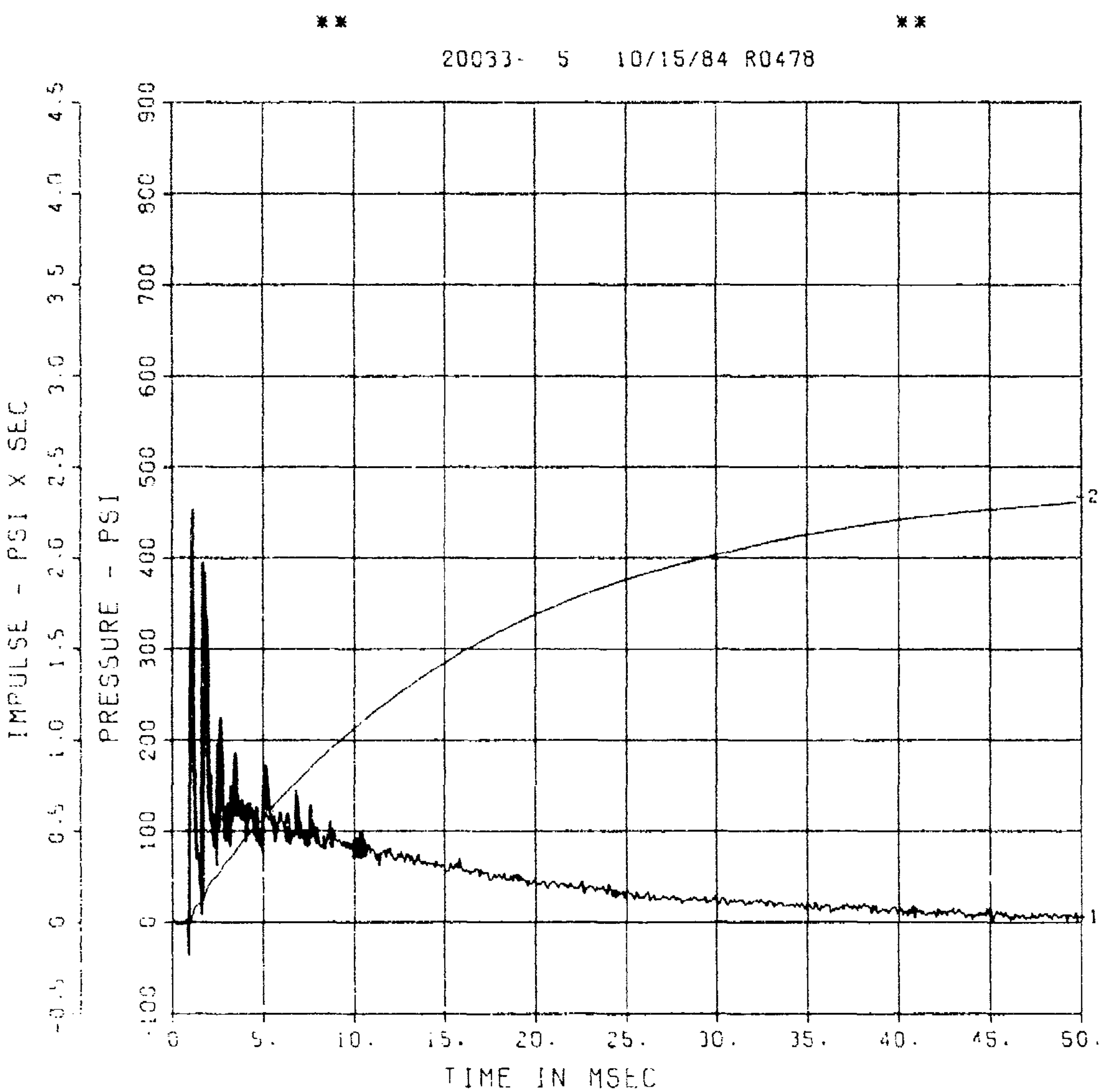
BP-3

200000. HZ CAL= 2087.

LP2/4 70% CUTOFF= 9000. HZ



FEMA YIELD EFFECTS 2
BP-5
200000. HZ CAL= 1843.
LP2/4 70% CUTOFF= 9000. HZ

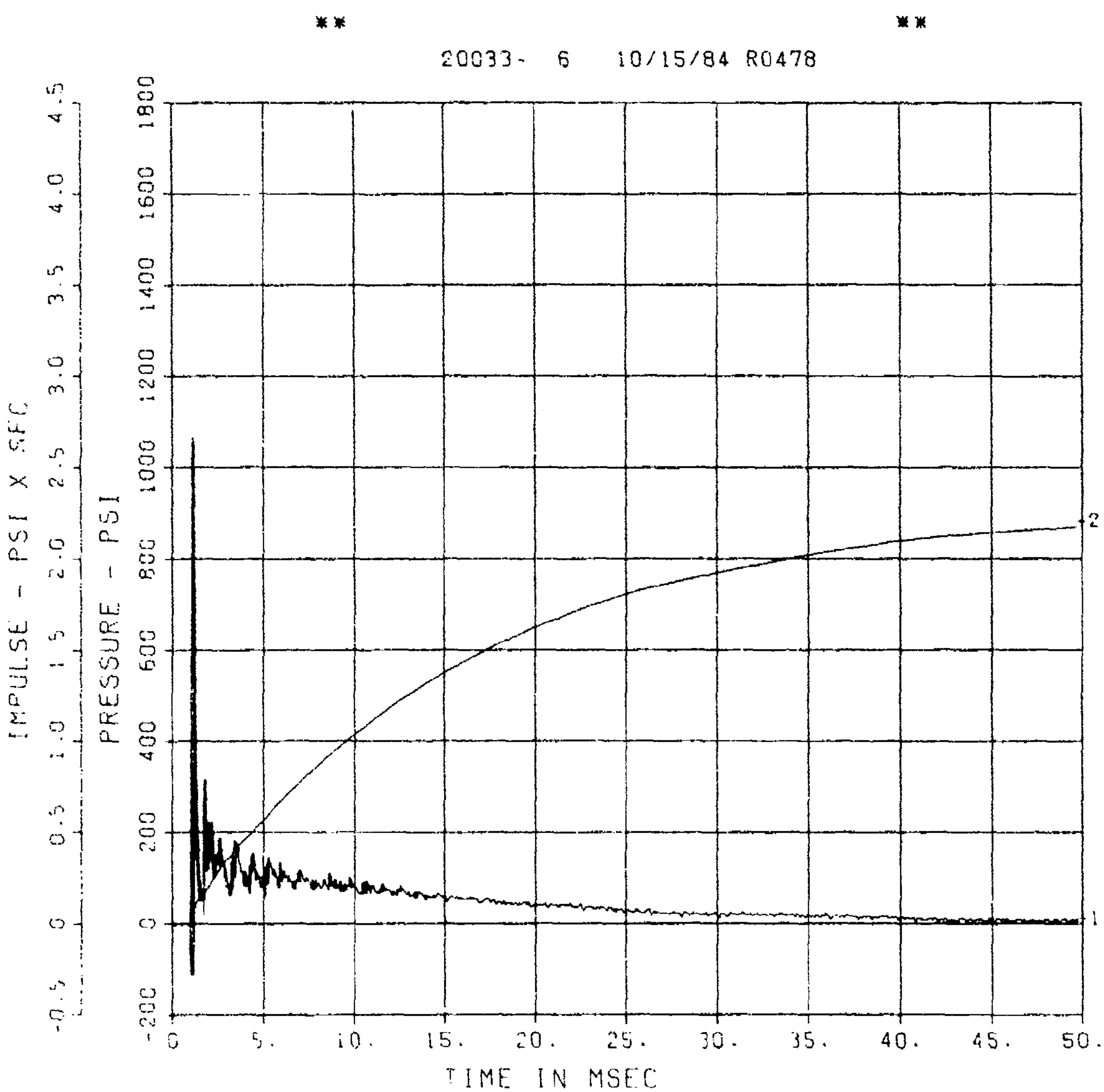


FEMA YIELD EFFECTS 2

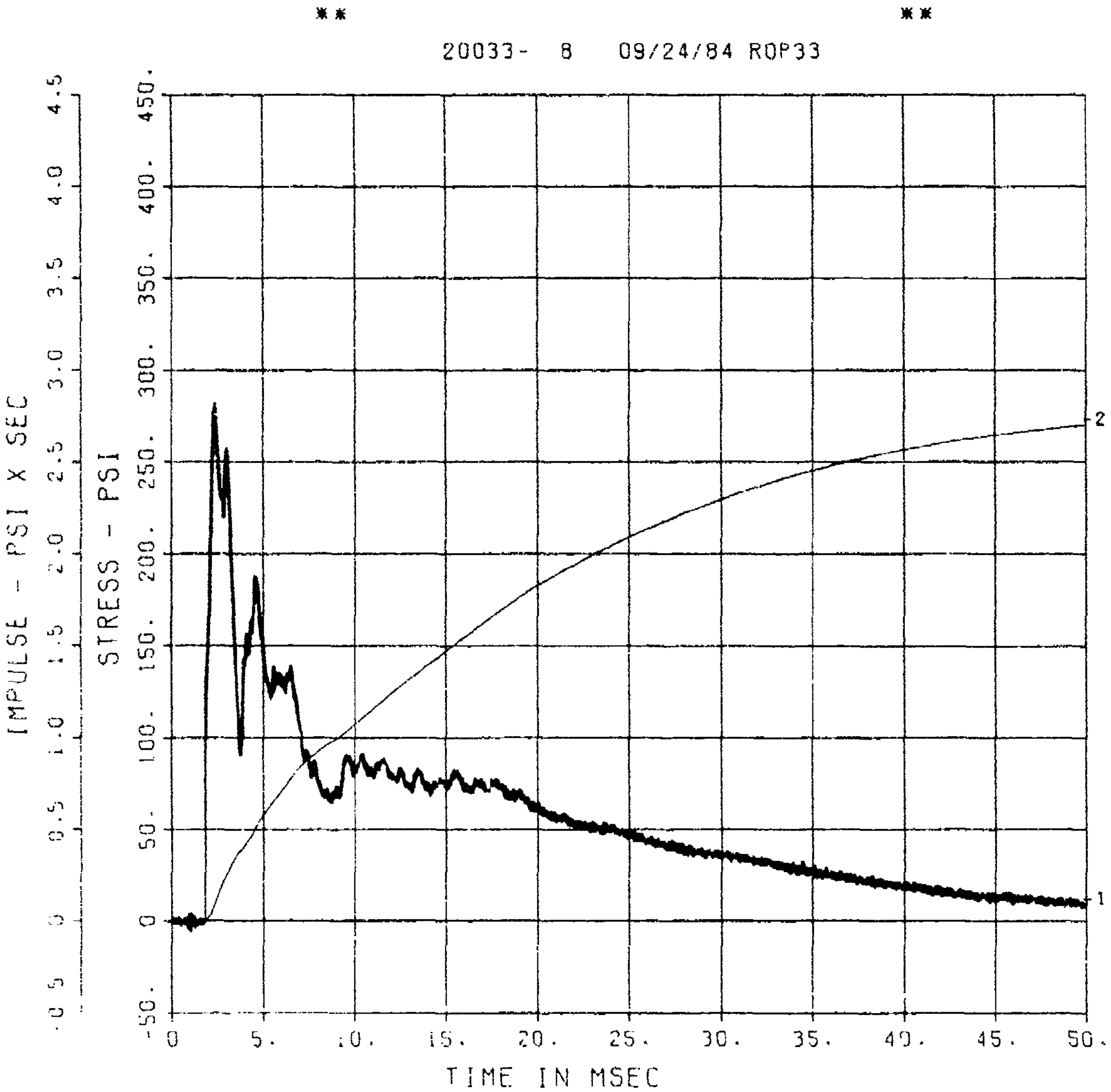
BP-6

200000. HZ CAL= 2164.

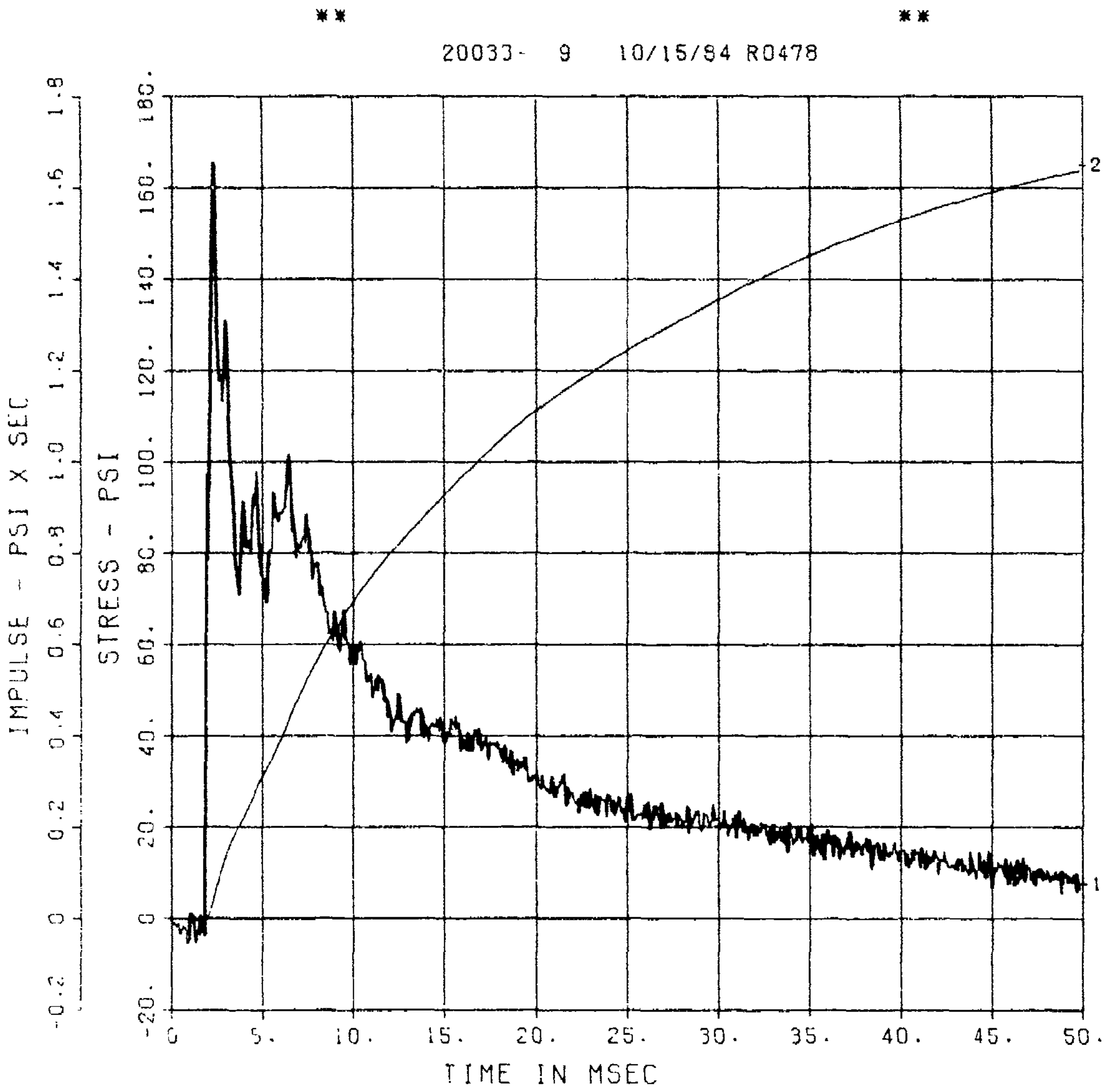
LP2/4 70% CUTOFF= 9000. HZ



FEMA YIELD EFFECTS 2
SE-2
200000. HZ CAL= 478.0



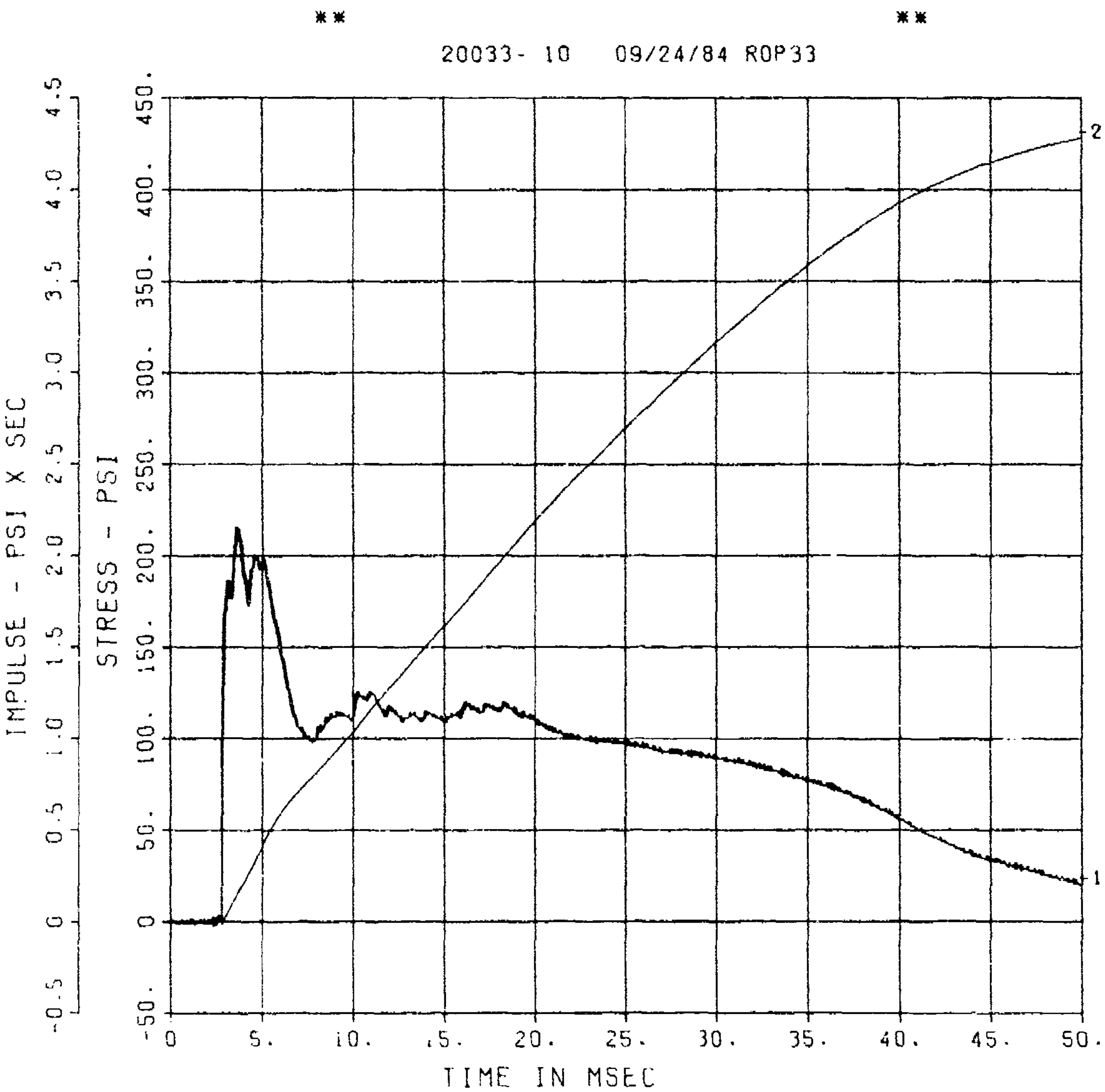
FEMA YIELD EFFECTS 2
SE-3
200000. HZ CAL= 994.0
LP4/0 70% CUTOFF= 9000. HZ



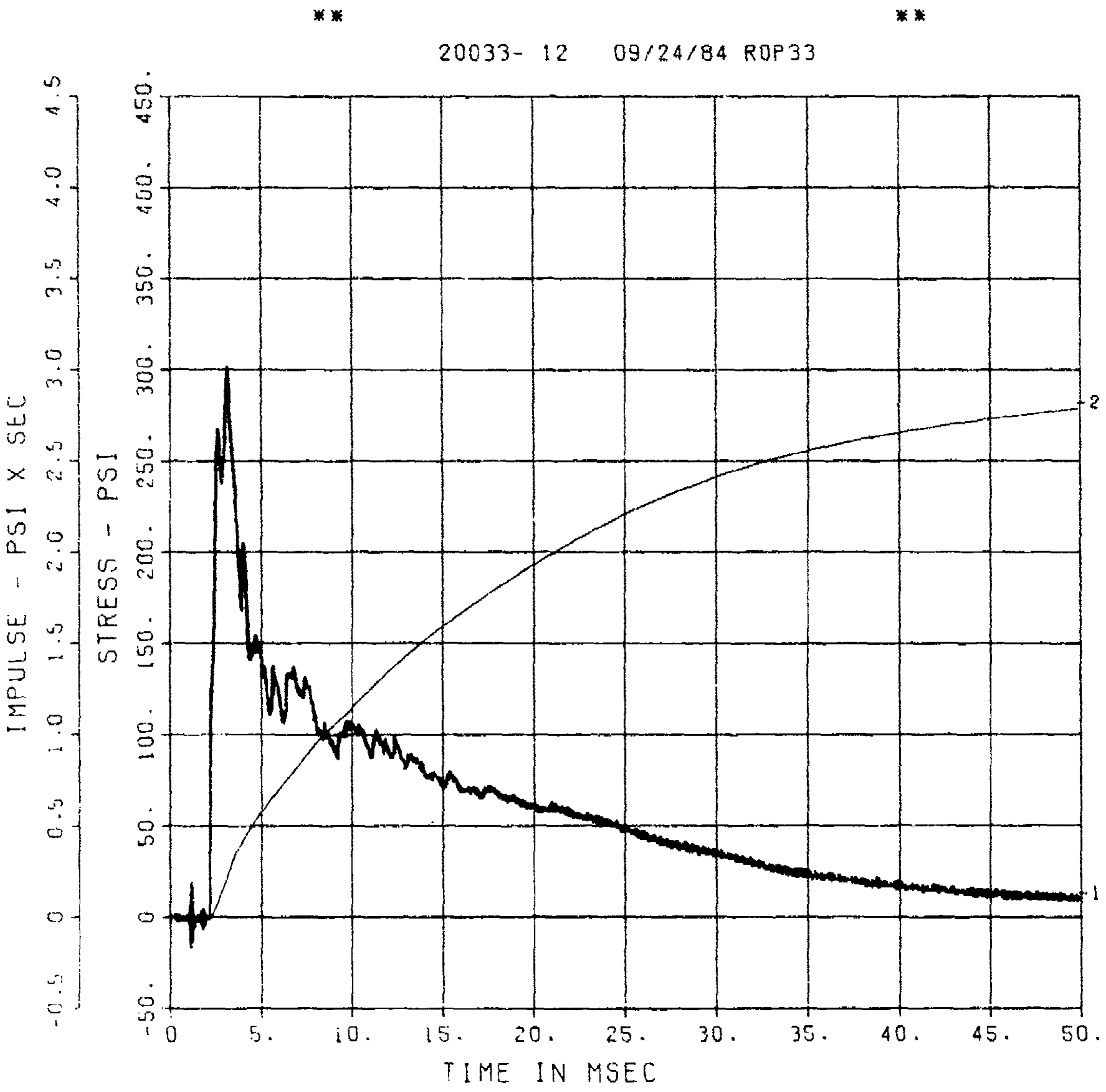
FEMA YIELD EFFECTS 2

SE-4

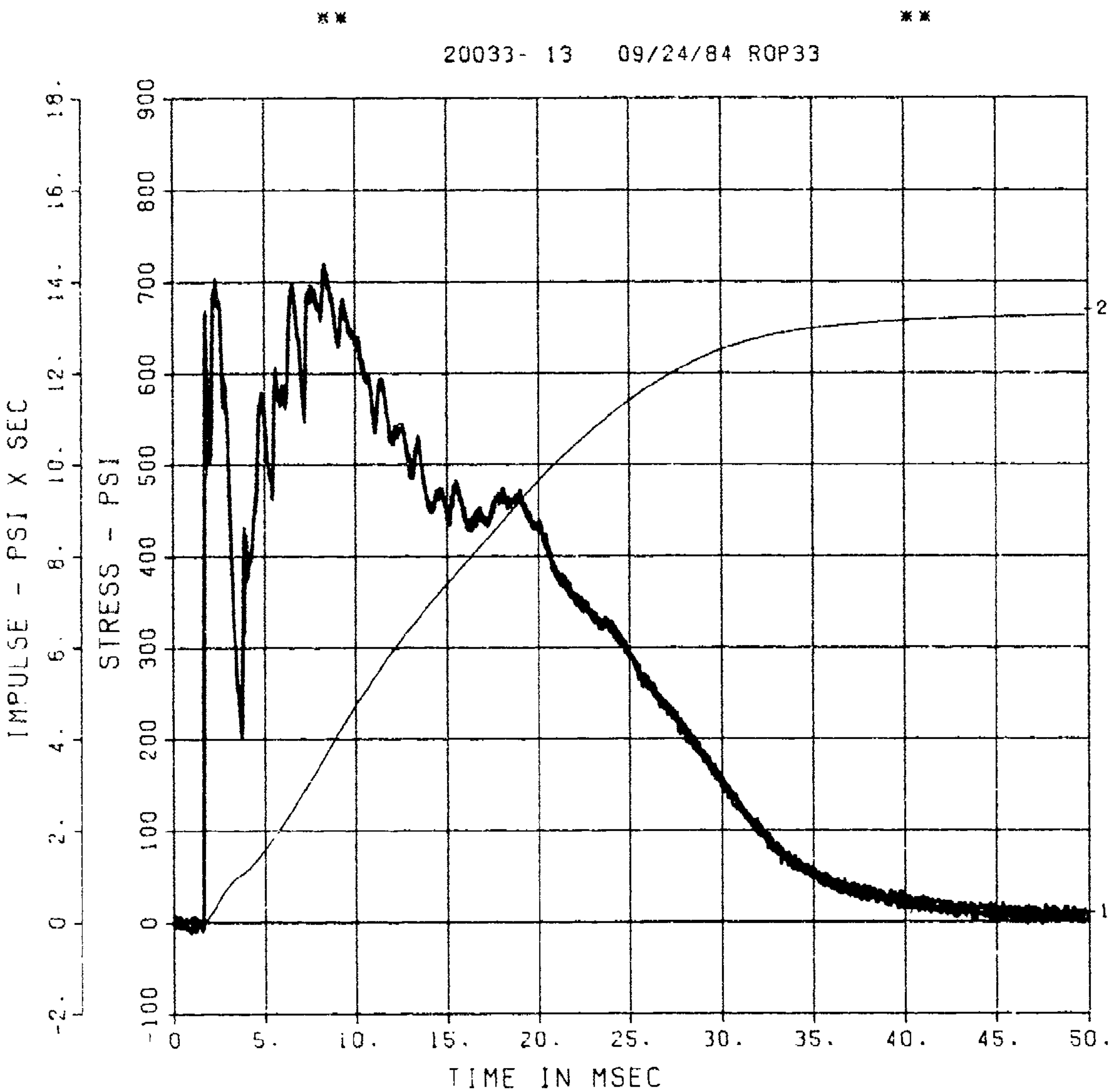
200000. HZ CAL= 243.0



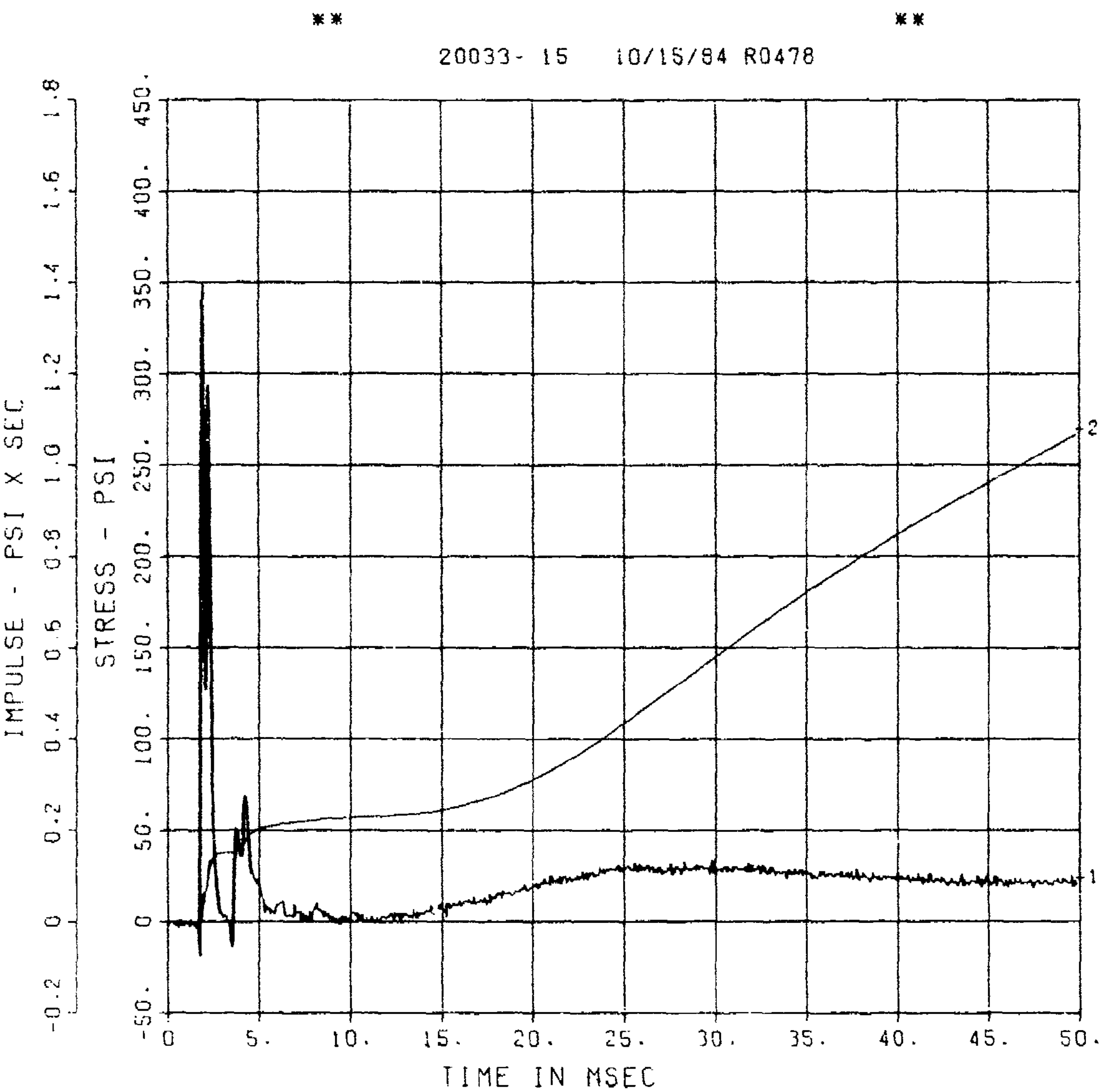
FEMA YIELD EFFECTS 2
SE-6
200000. HZ CAL= 371.0



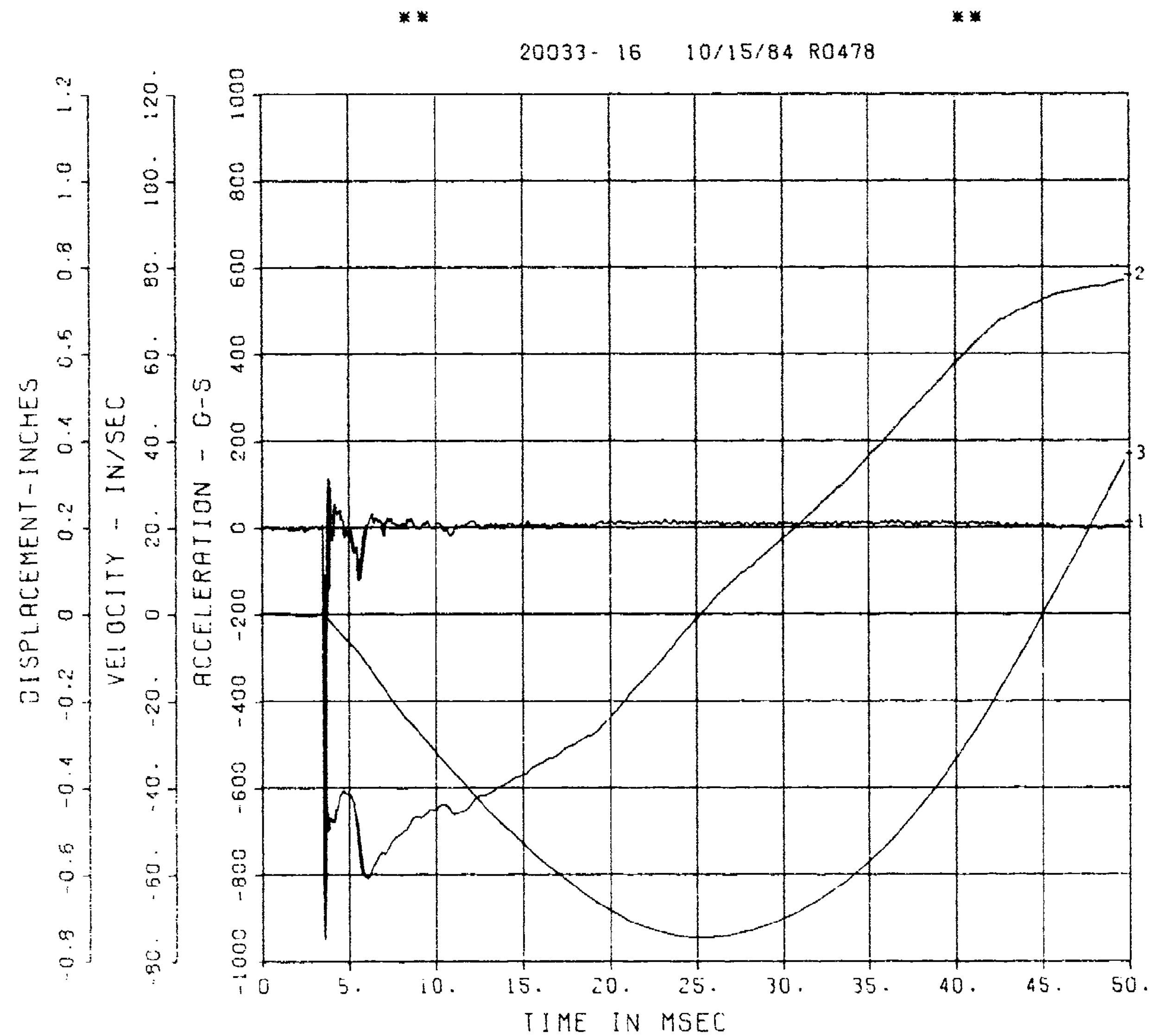
FEMA YIELD EFFECTS 2
SE-7
200000. HZ CAL= 1115.



FEMA YIELD EFFECTS 2
SE-9
200000. HZ CAL= 773.0
LP2/0 70% CUTOFF= 18000. HZ



FEMA YIELD EFFECTS 2
AFF-1
200000. HZ CAL= 1967.
LP4/4 70% CUTOFF= 9000. HZ

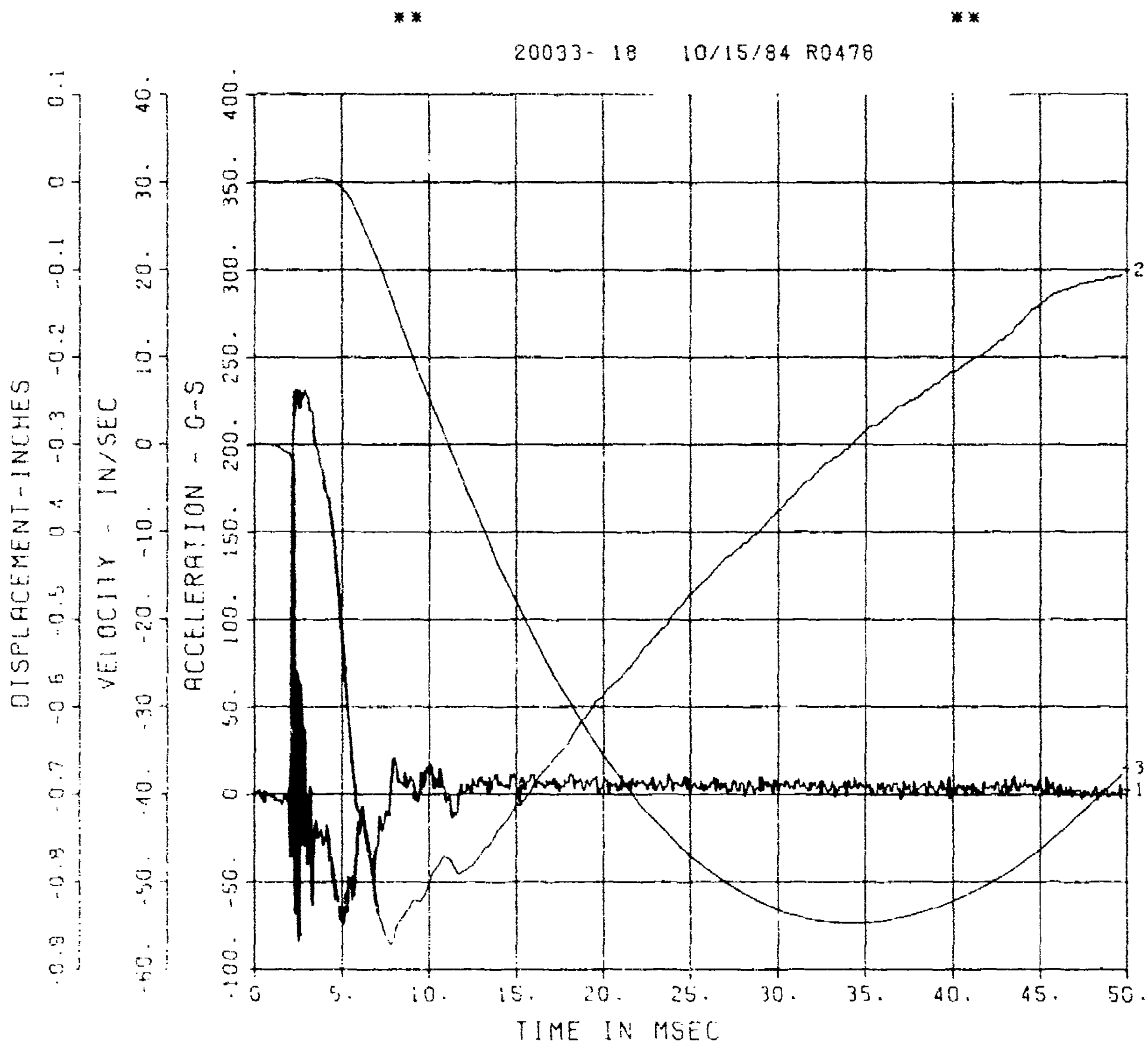


FEMA YIELD EFFECTS 2

A-2

200000. HZ CAL= 1440.

LP4/4 70% CUTOFF= 9000. HZ

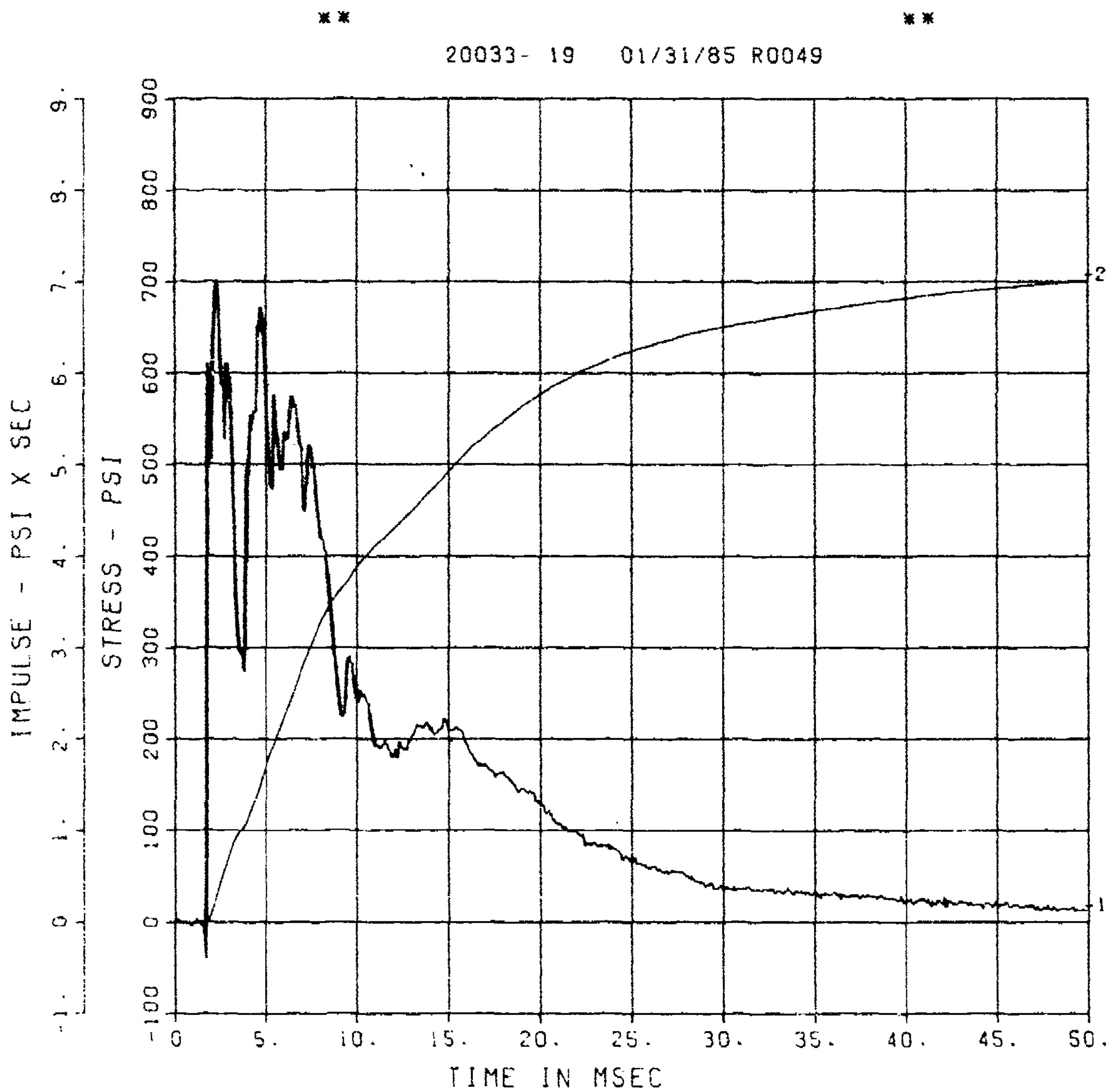


FEMA YIELD EFFECTS 2

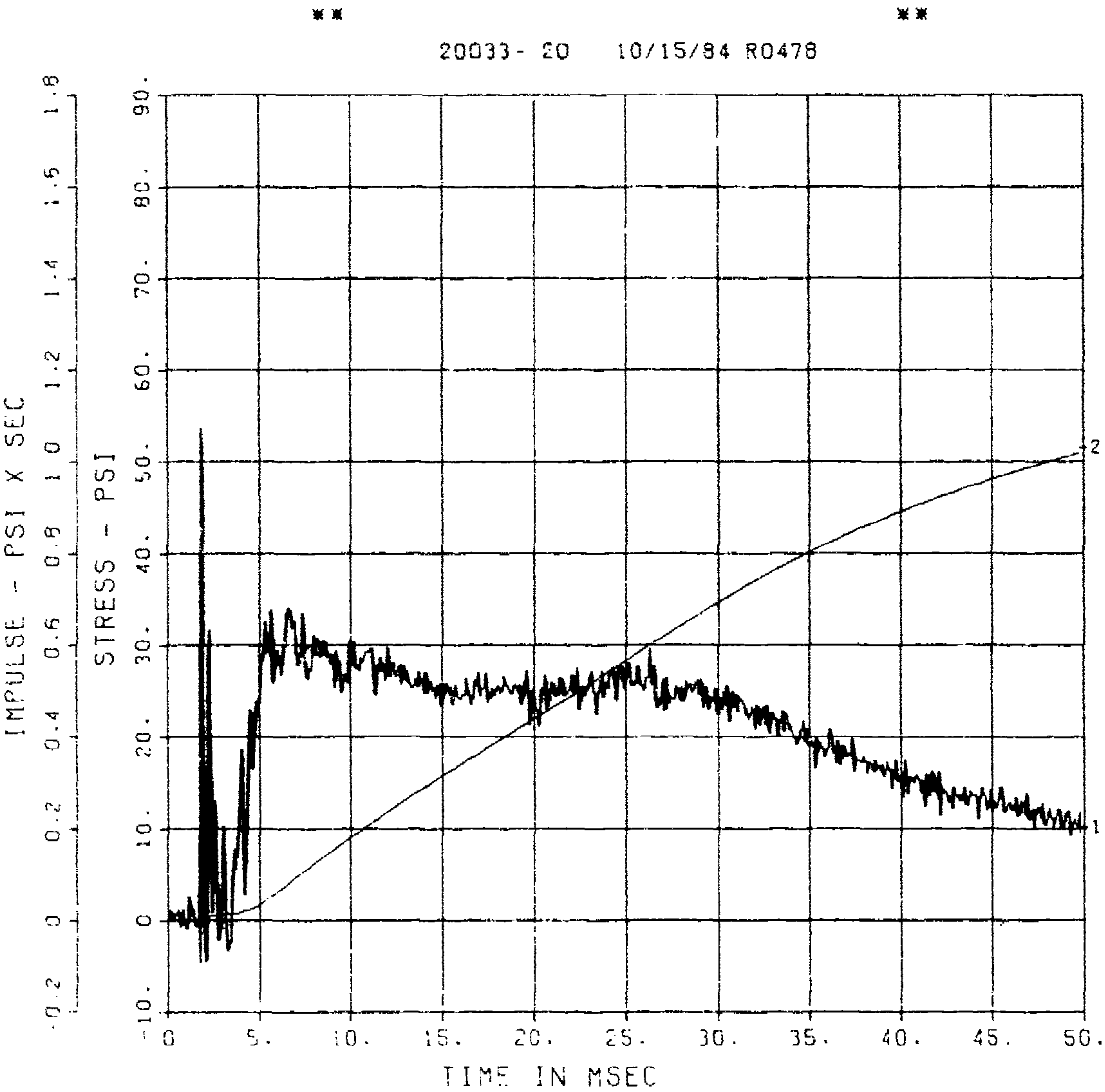
IF-1

200000. HZ CAL= 1160.

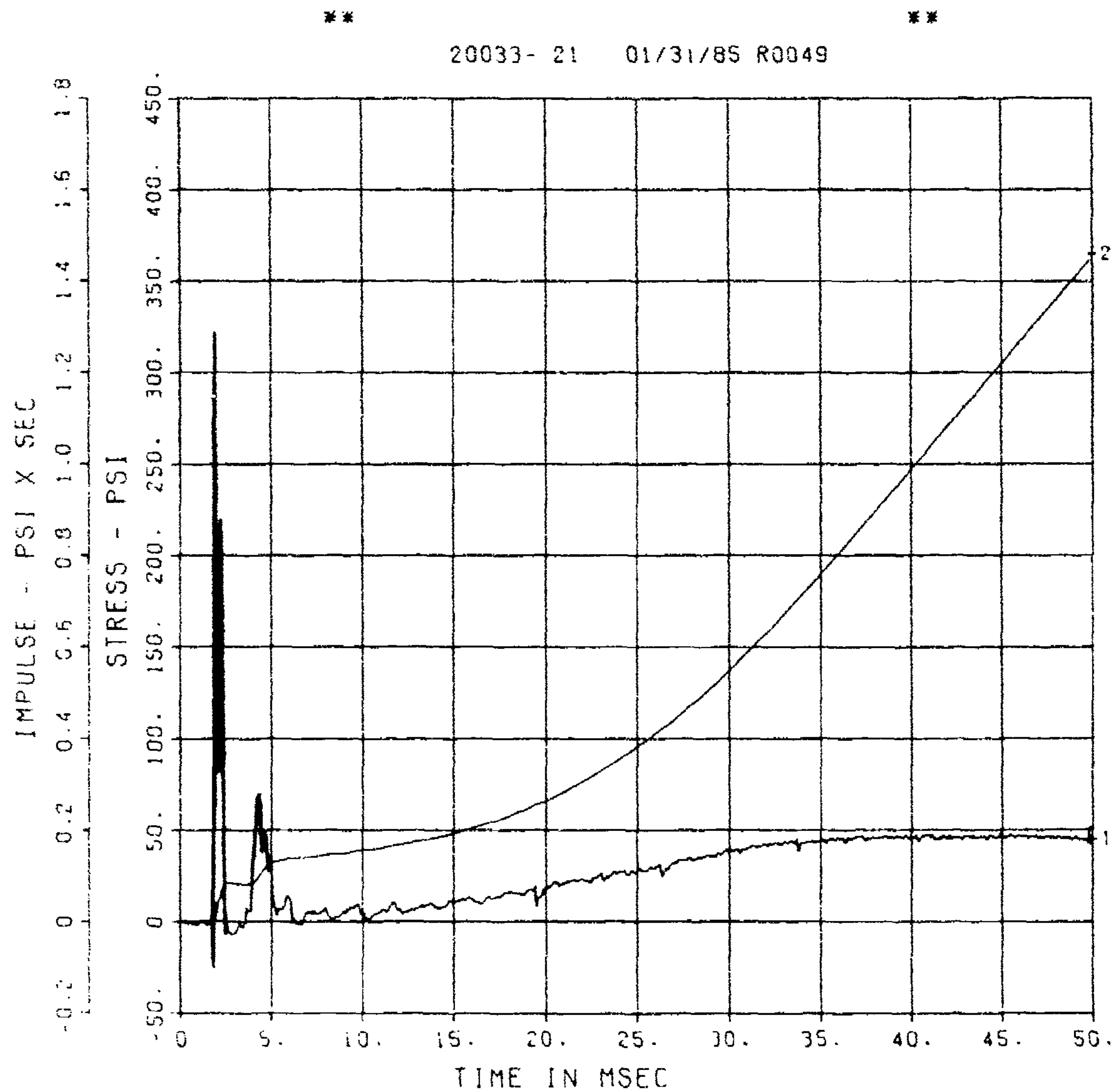
LP4/0 70% CUTOFF= 9000. HZ



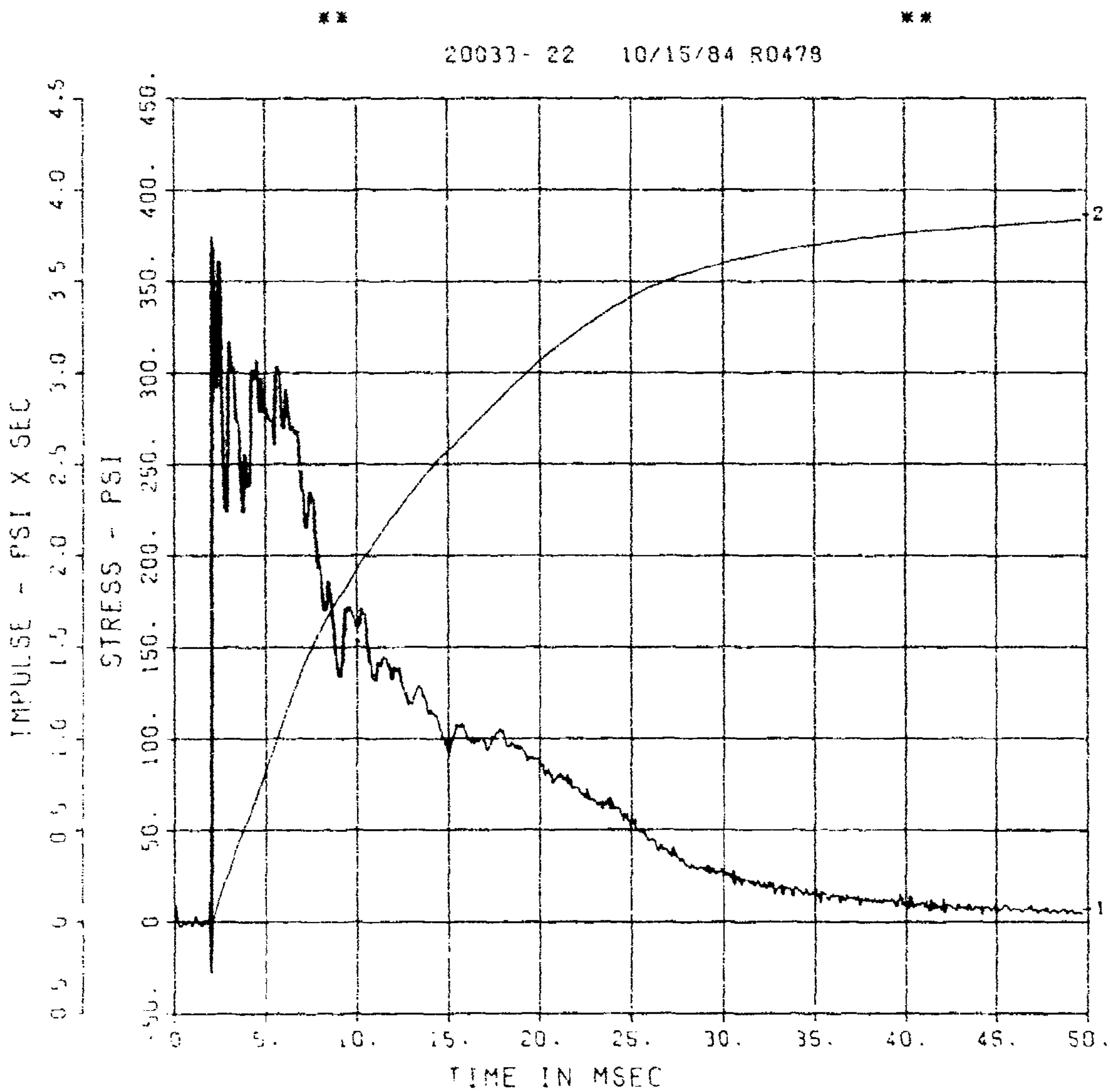
FEMA YIELD EFFECTS 2
IF-2
200000. HZ CAL= 592.0
LP4/4 70% CUTOFF= 9000. HZ



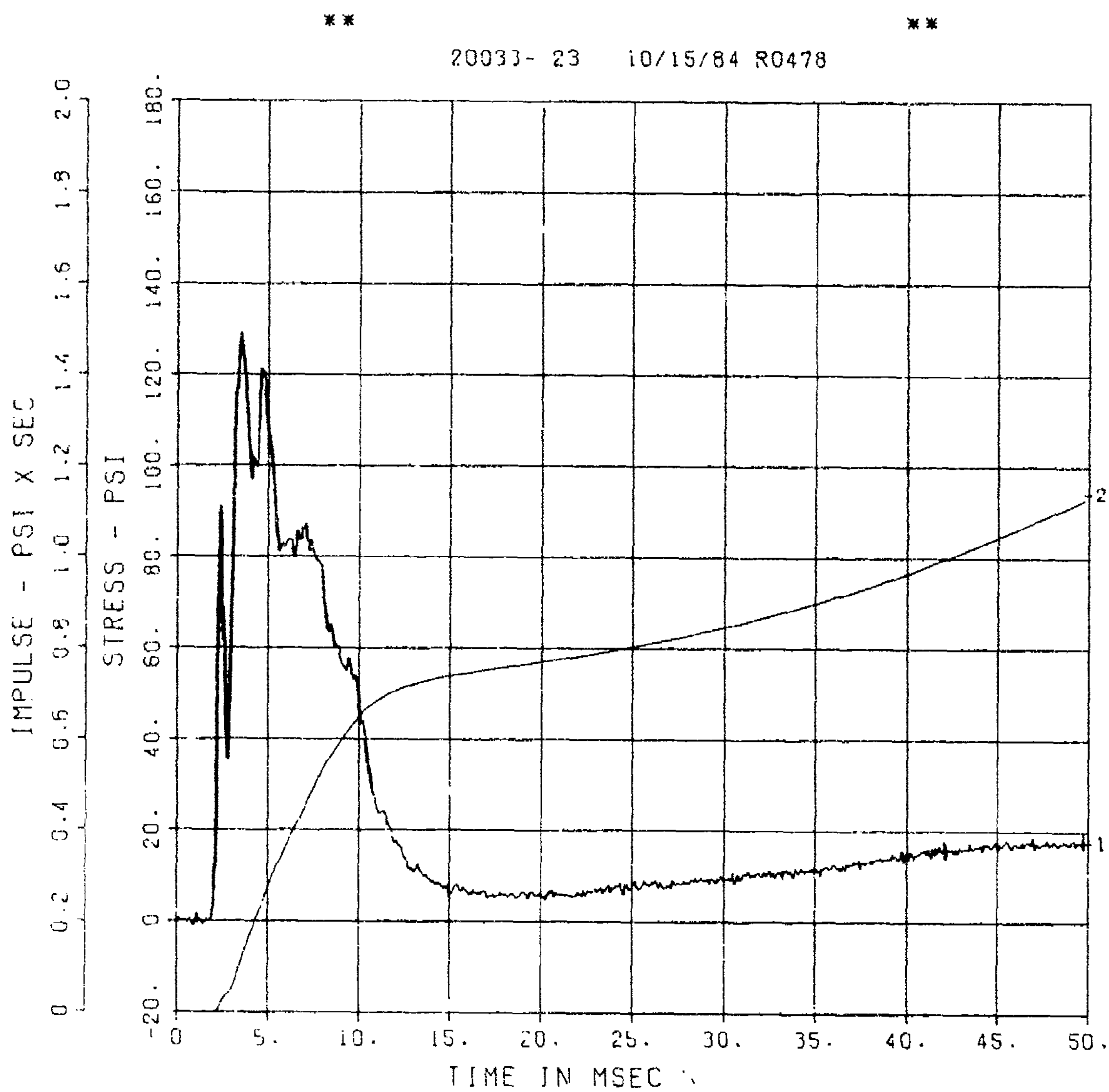
FEMA YIELD EFFECTS 2
IF-3
200000. HZ CAL= 569.0
LP4/0 70% CUTOFF= 9000. HZ



FEMA YIELD EFFECTS 2
IF-4
200000. HZ CAL= 980.0
LP2/4 70% CUTOFF= 9000. HZ



FEMA YIELD EFFECTS 2
IF-5
200000. HZ CAL= 356.0
LP2/4 70% CUTOFF= 9000. HZ

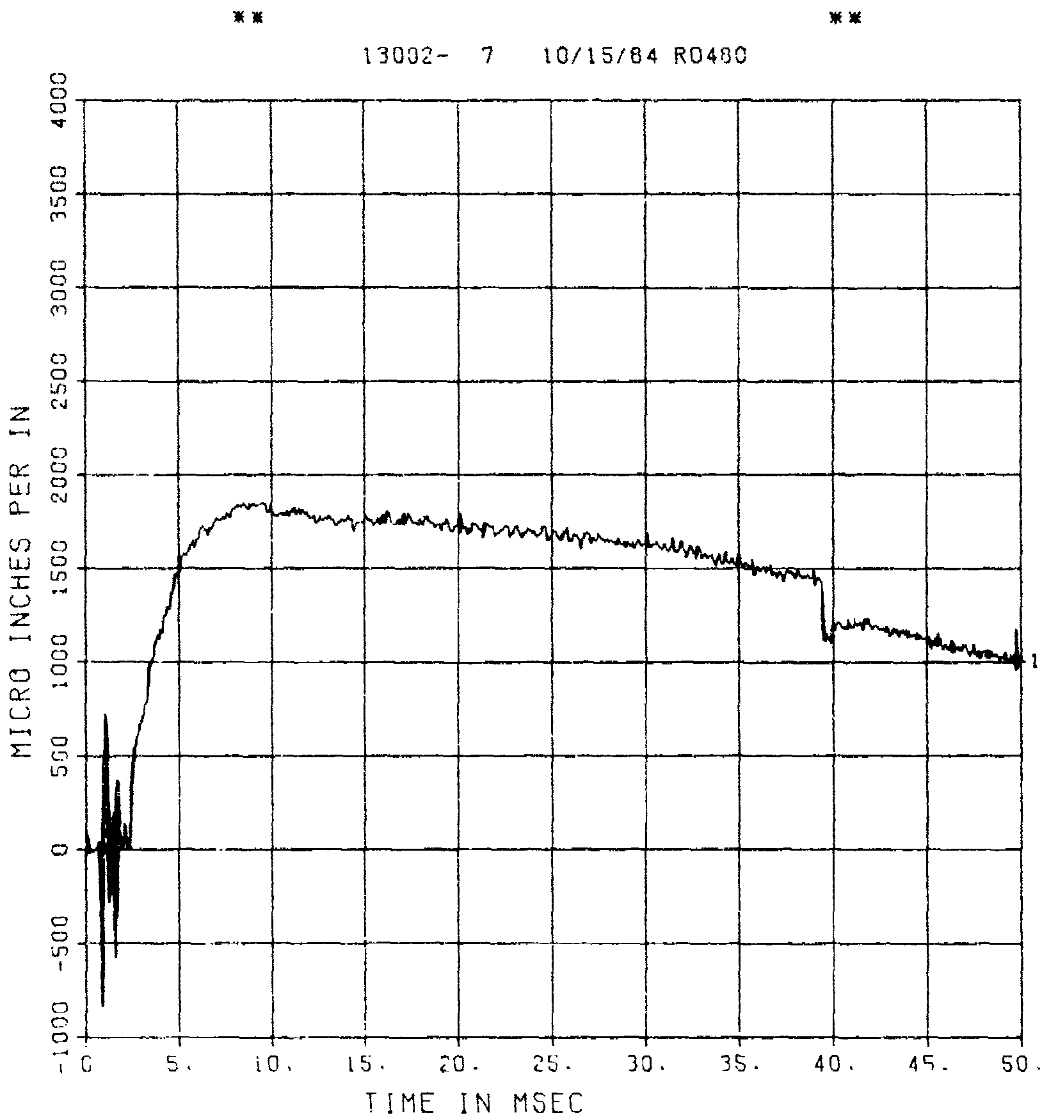


FEMA YIELD EFFECTS 2

E0-1A

200000. HZ CAL= 9975.

LP4/0 70% CUTOFF= 9000. HZ

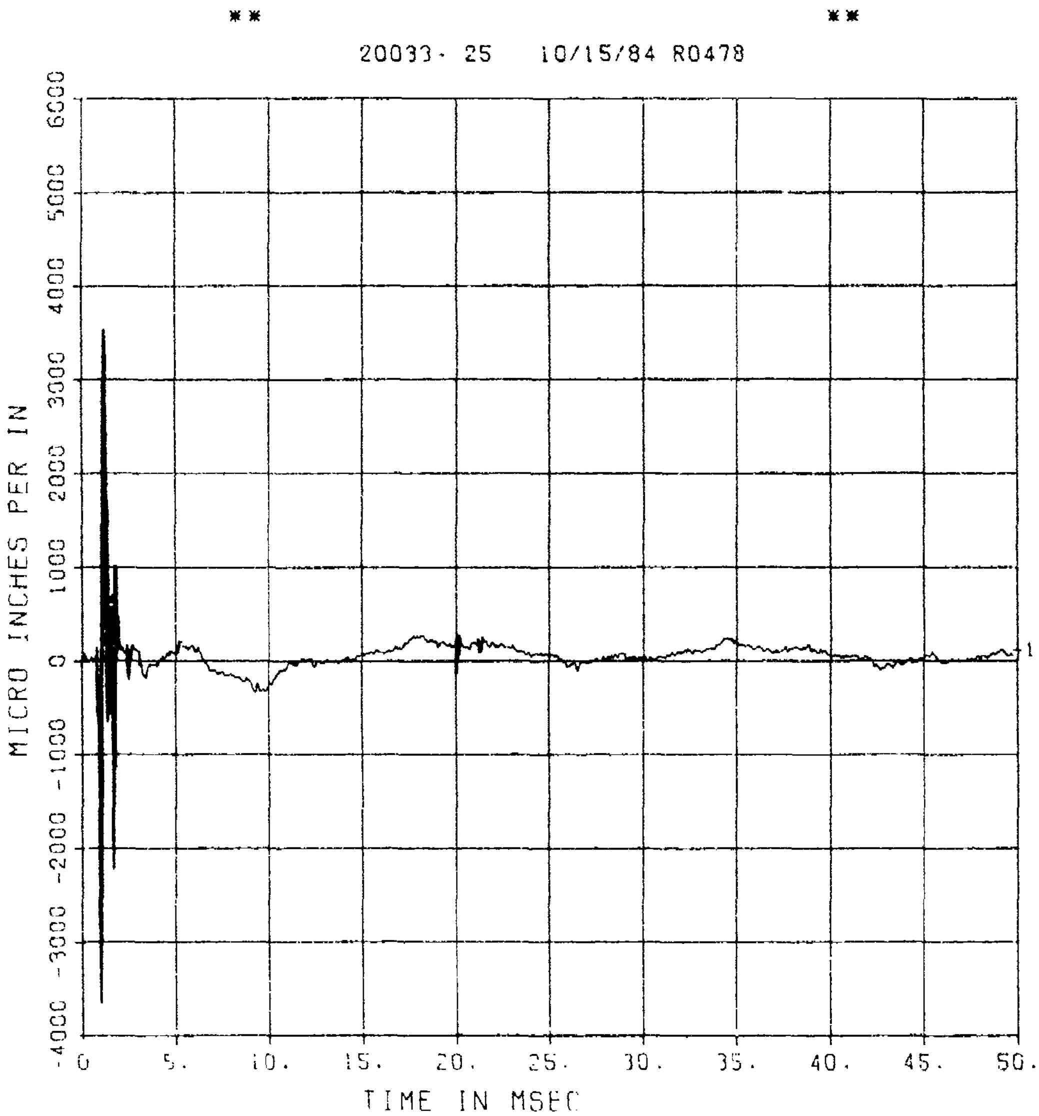


FEMA YIELD EFFECTS 2

EI-1

200000. HZ CAL= 9975.

LP4/4 70% CUTOFF= 9000. HZ

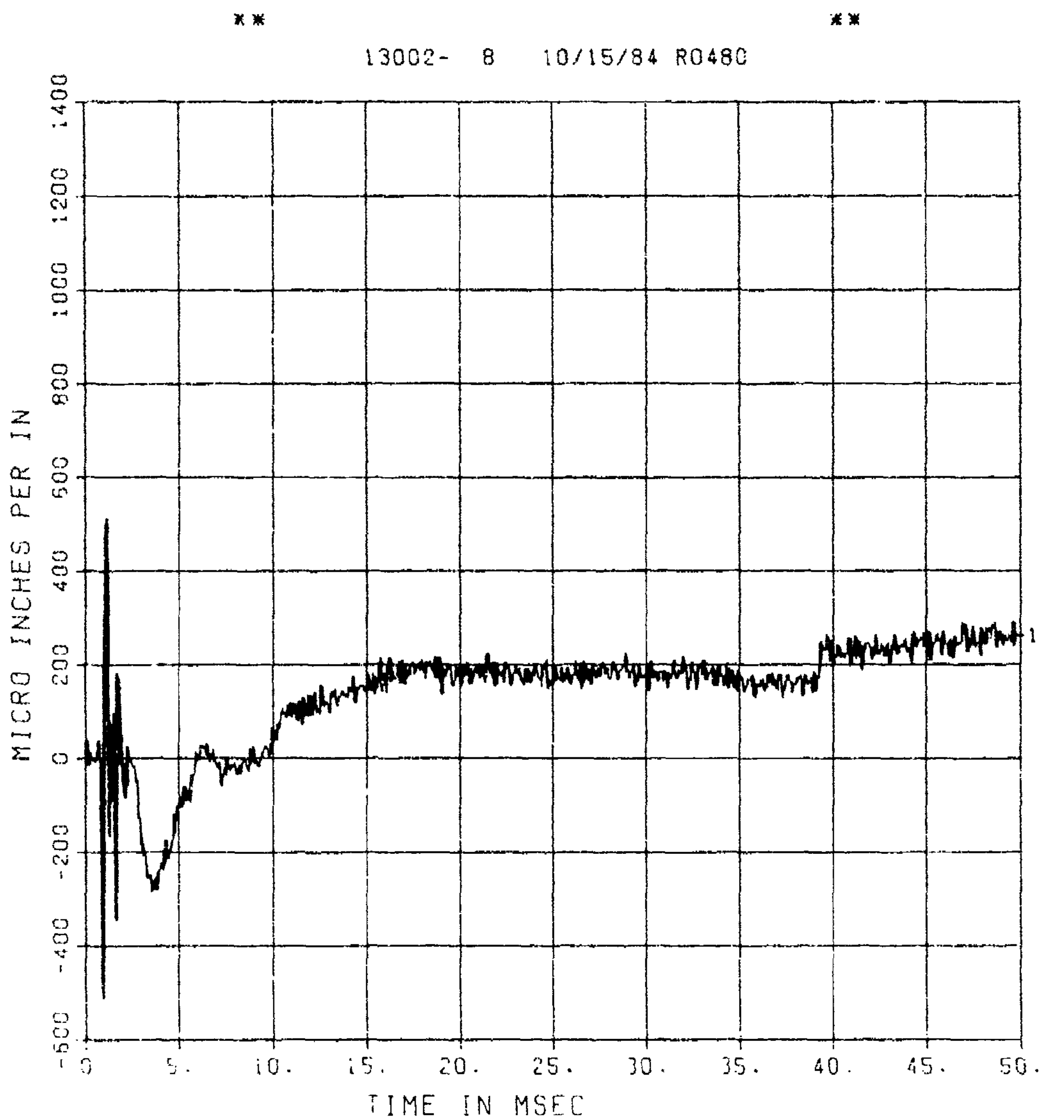


FEMA YIELD EFFECTS 2

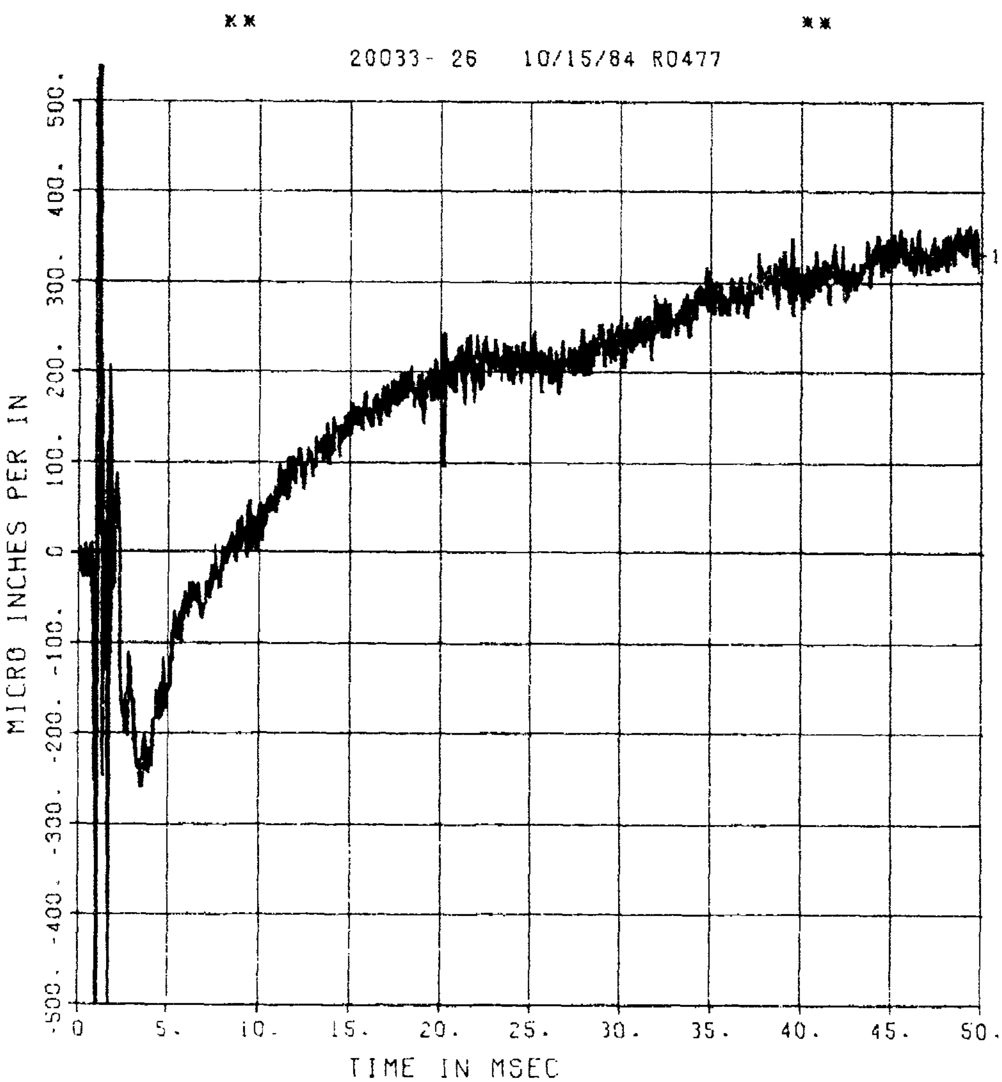
EI-1A

200000. HZ   CAL= 9975.

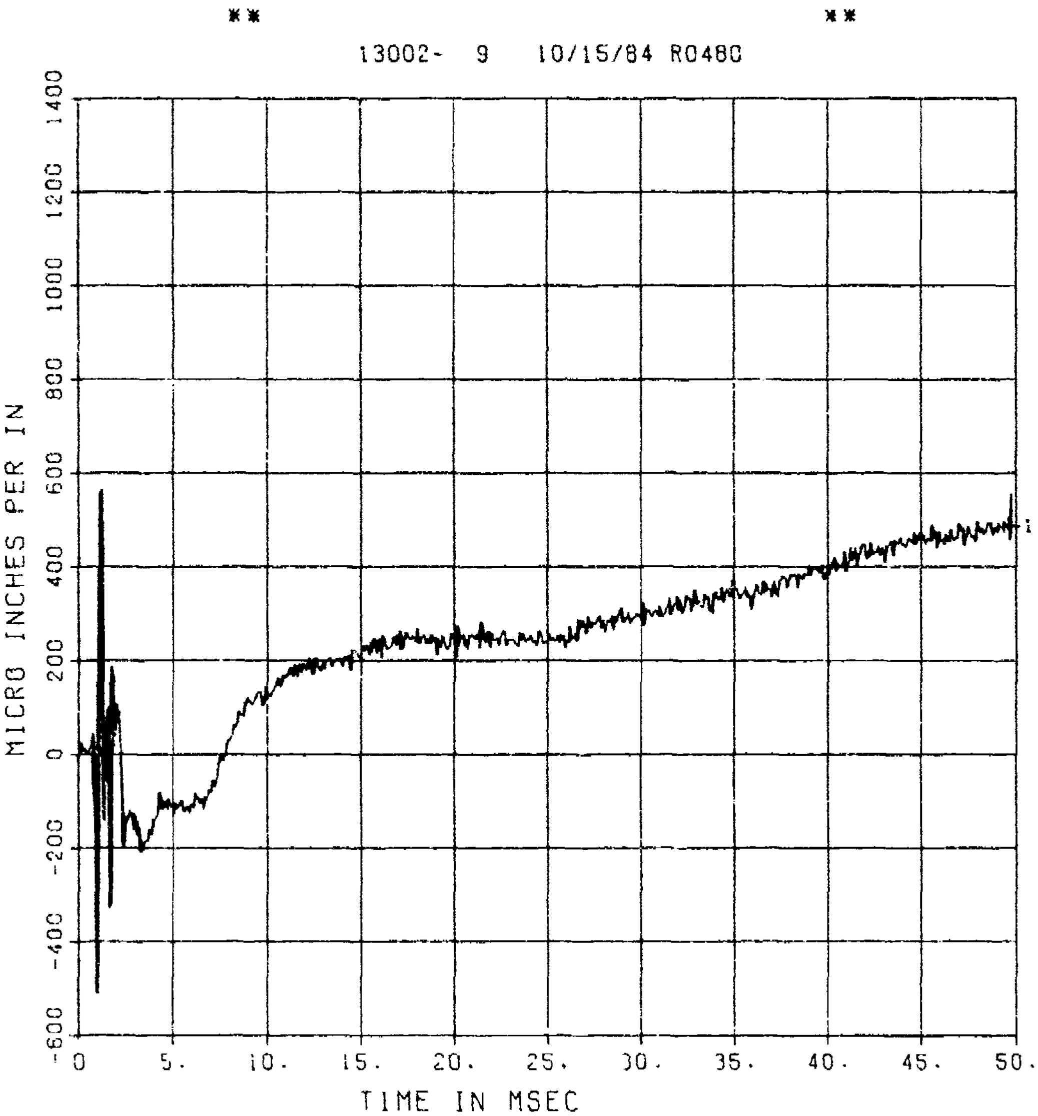
LP4/4 70% CUTOFF= 9000. HZ



FEMA YIELD EFFECTS 2
EO-2
200000. HZ CAL= 6667.
LP2/2 70% CUTOFF= 18000. HZ



FEMA YIELD EFFECTS 2
EO-2A
200000. HZ CAL= 6667.
LP4/4 70% CUTOFF= 9000. HZ



FEMA YIELD EFFECTS 2

EI-2

200000. HZ CAL= 6667.

LP4/4 70% CUTOFF= 9000. HZ

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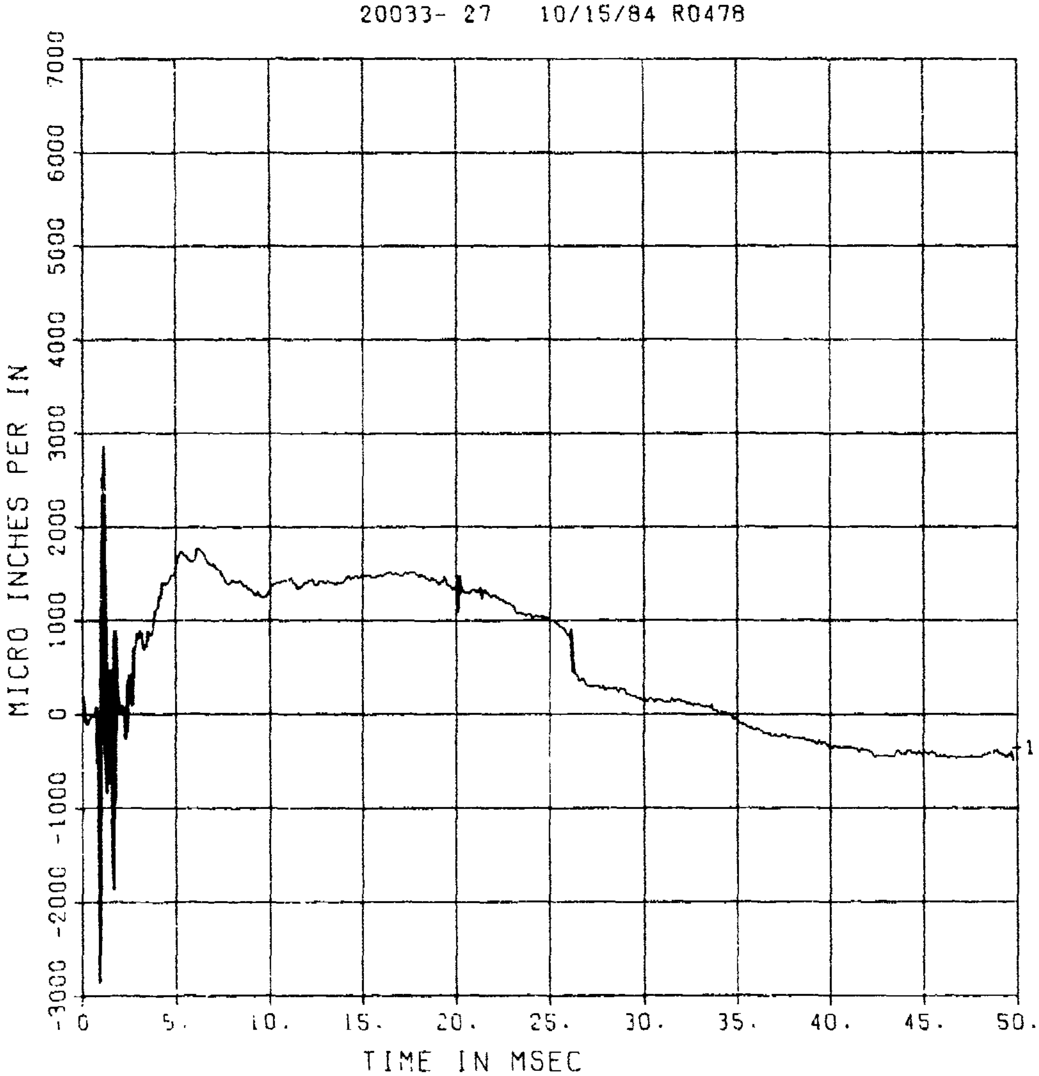
20033- 27 10/15/84 R0478



FEMA YIELD EFFECTS 2

EI-2A

200000. HZ CAL= 6667.

LP4/4 70% CUTOFF= 9000. HZ

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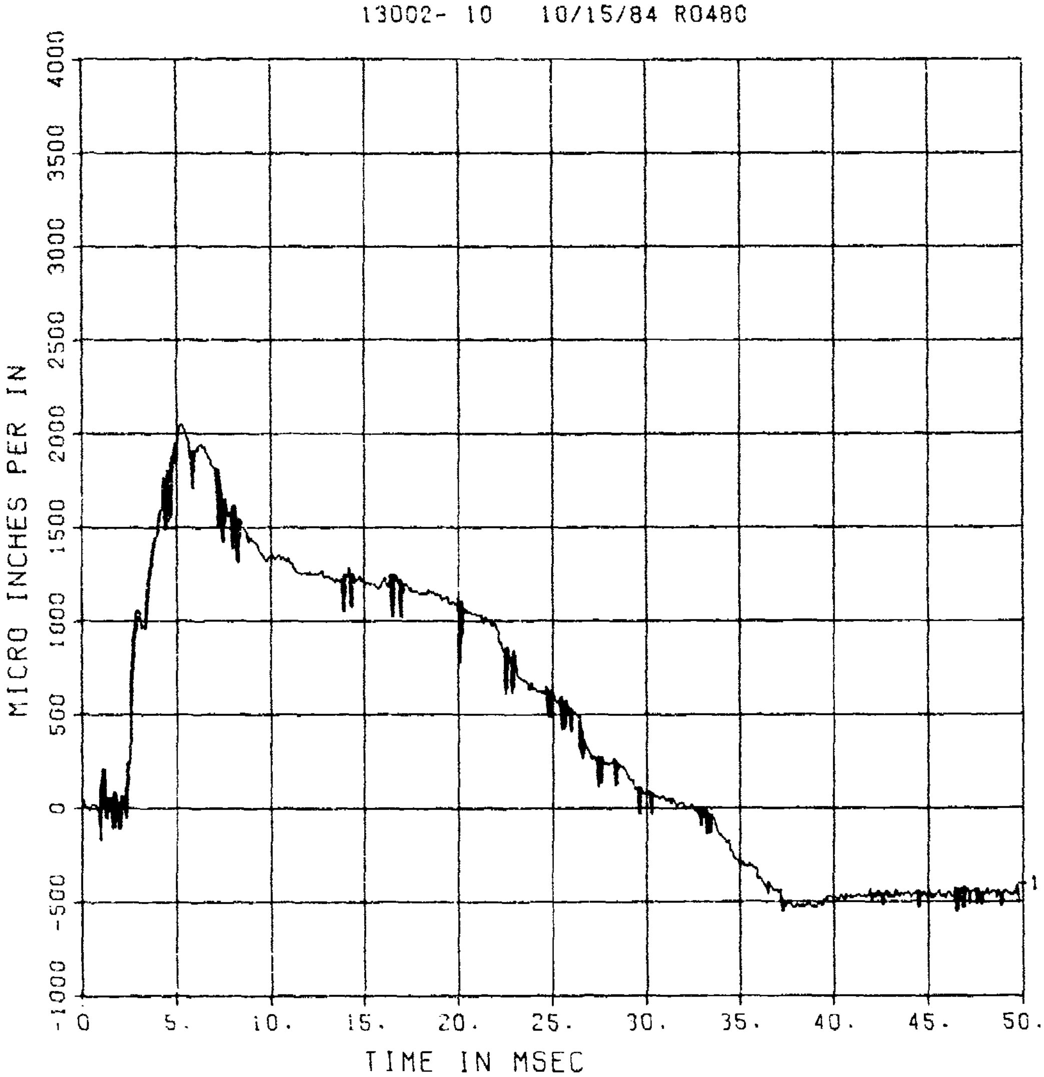
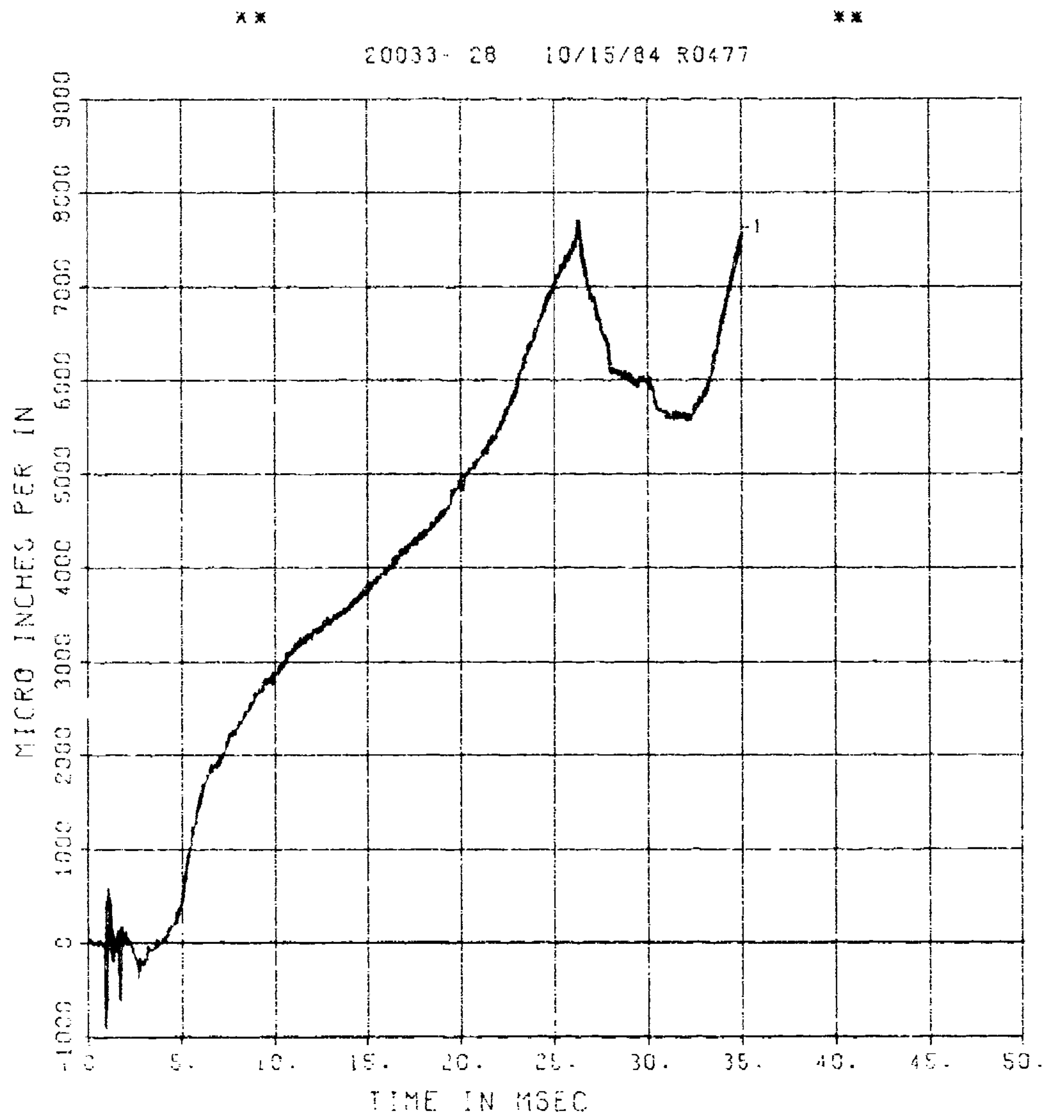
13002- 10 10/15/84 R0480



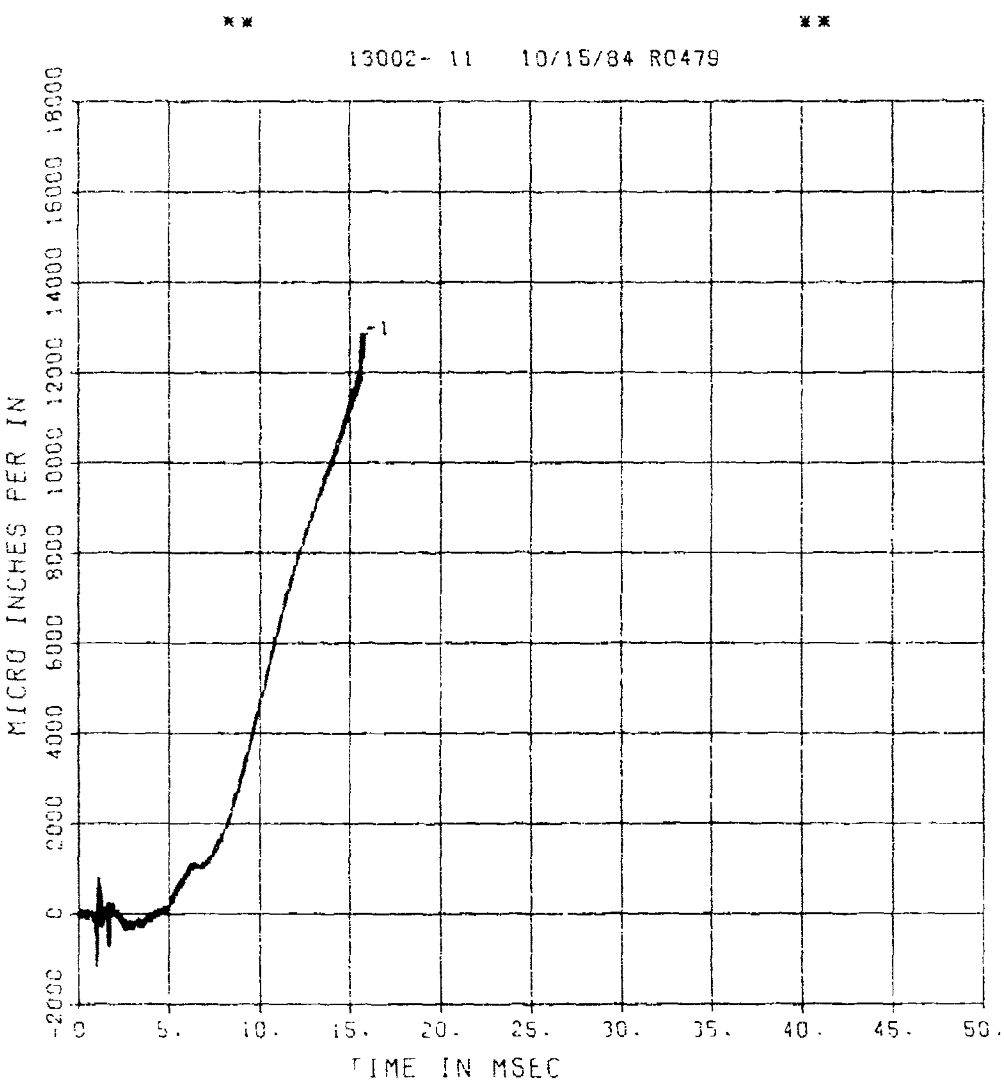
FEMA YIELD EFFECTS 2

EO-3

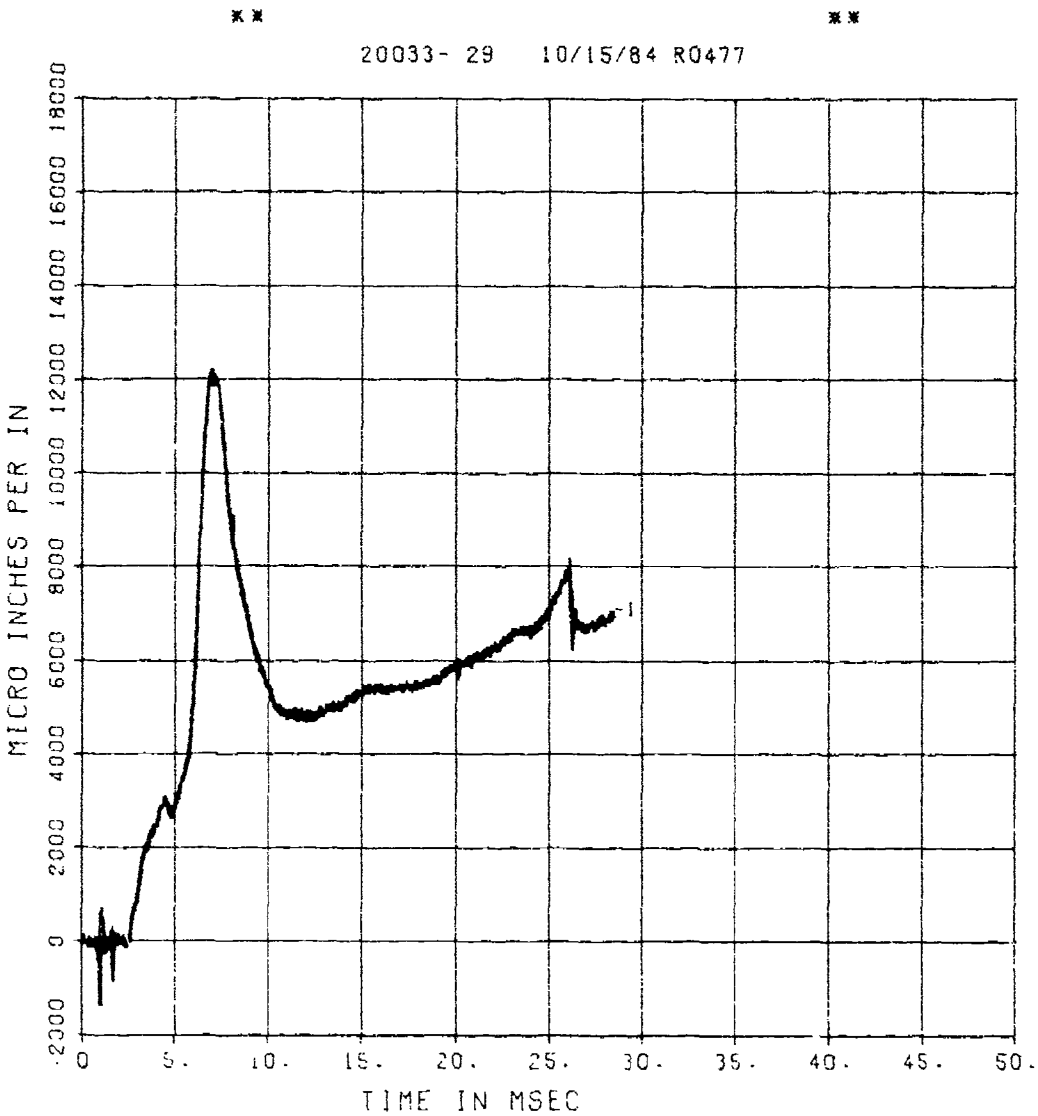
200000. HZ CAL= 6667.



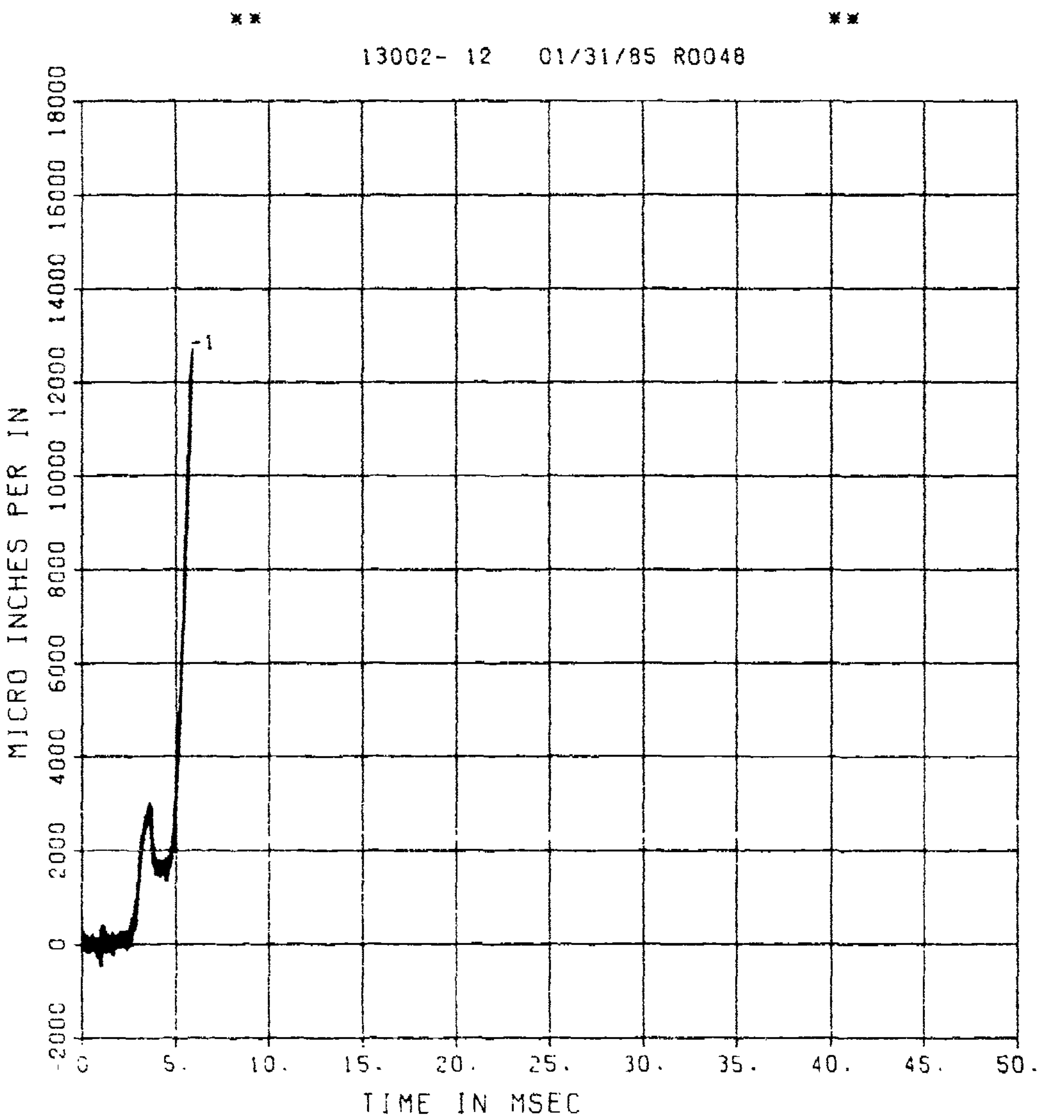
FEMA YIELD EFFECTS 2
EO-3A
200000. HZ CAL= 6667.



FEMA YIELD EFFECTS 2
EI-3
200000. HZ CAL= 19613.



FEMA YIELD EFFECTS 2
EI-3A
200000. HZ CAL= 19613.

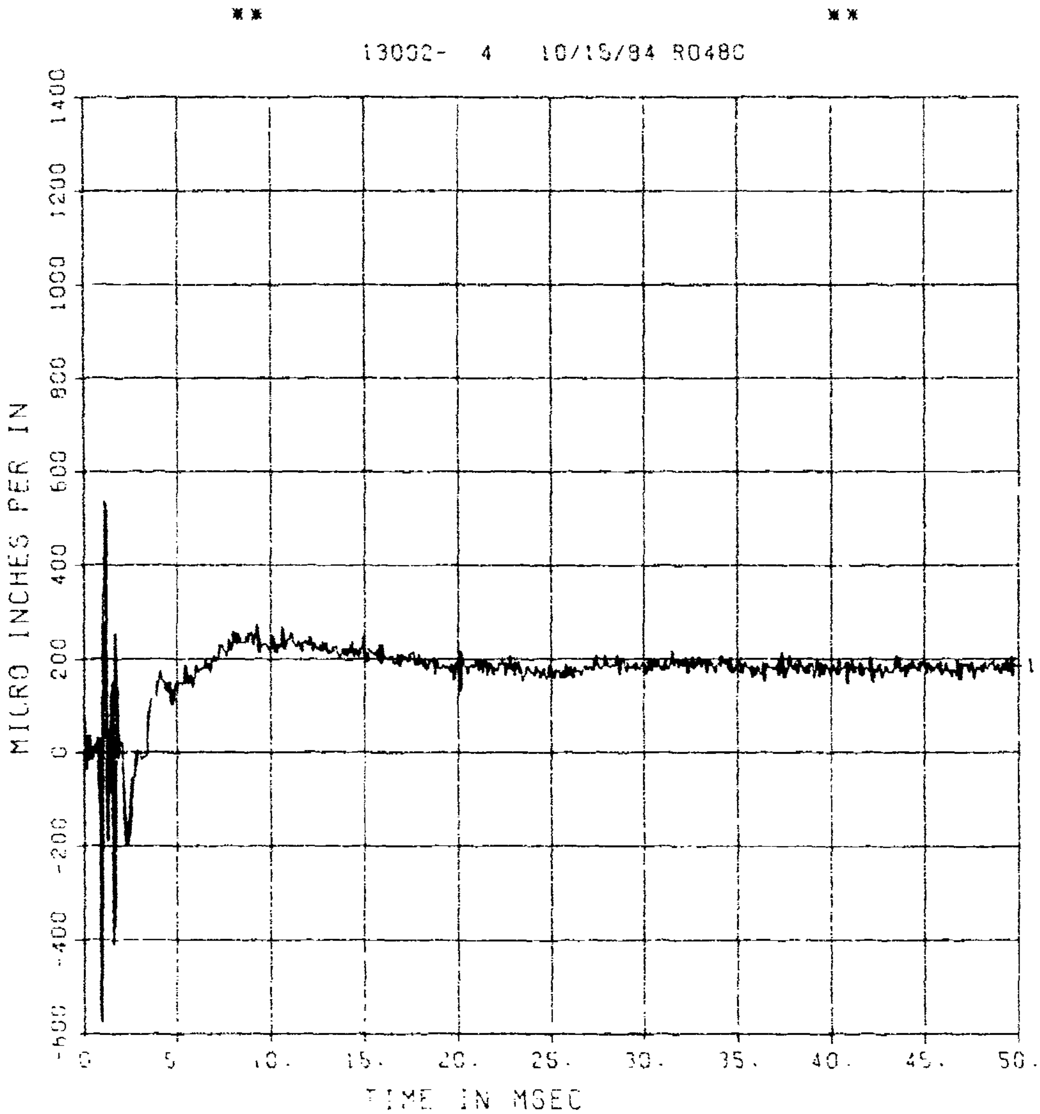


FEMA YIELD EFFECTS 2

EI-4

200000. HZ CAL= 6667.

LP2/4 70% CUTOFF= 9000. HZ

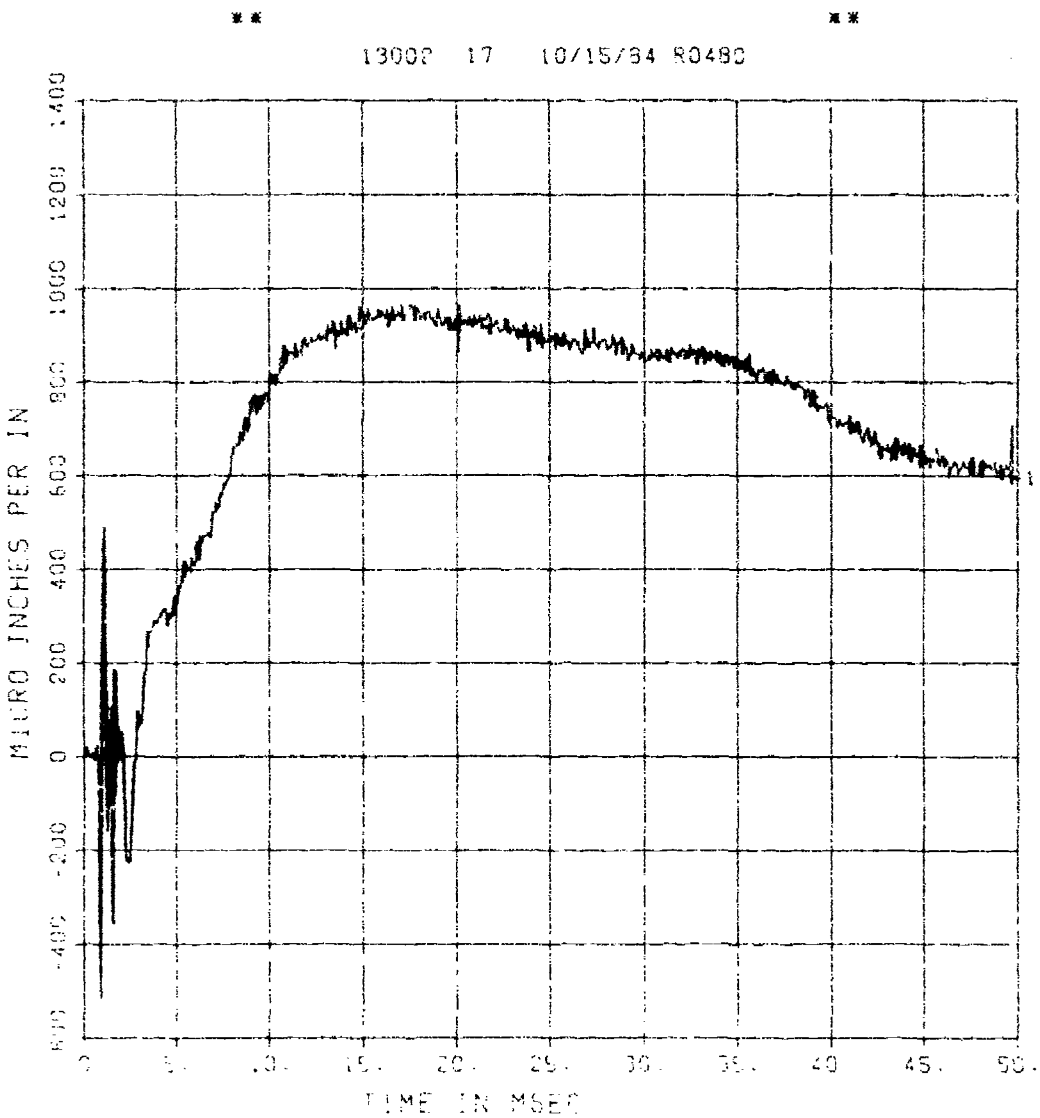


FEMA YIELD EFFECTS 2

EI-4A

200000. HZ CAL= 6667.

LP2/4 70% CUTOFF= 9000. HZ

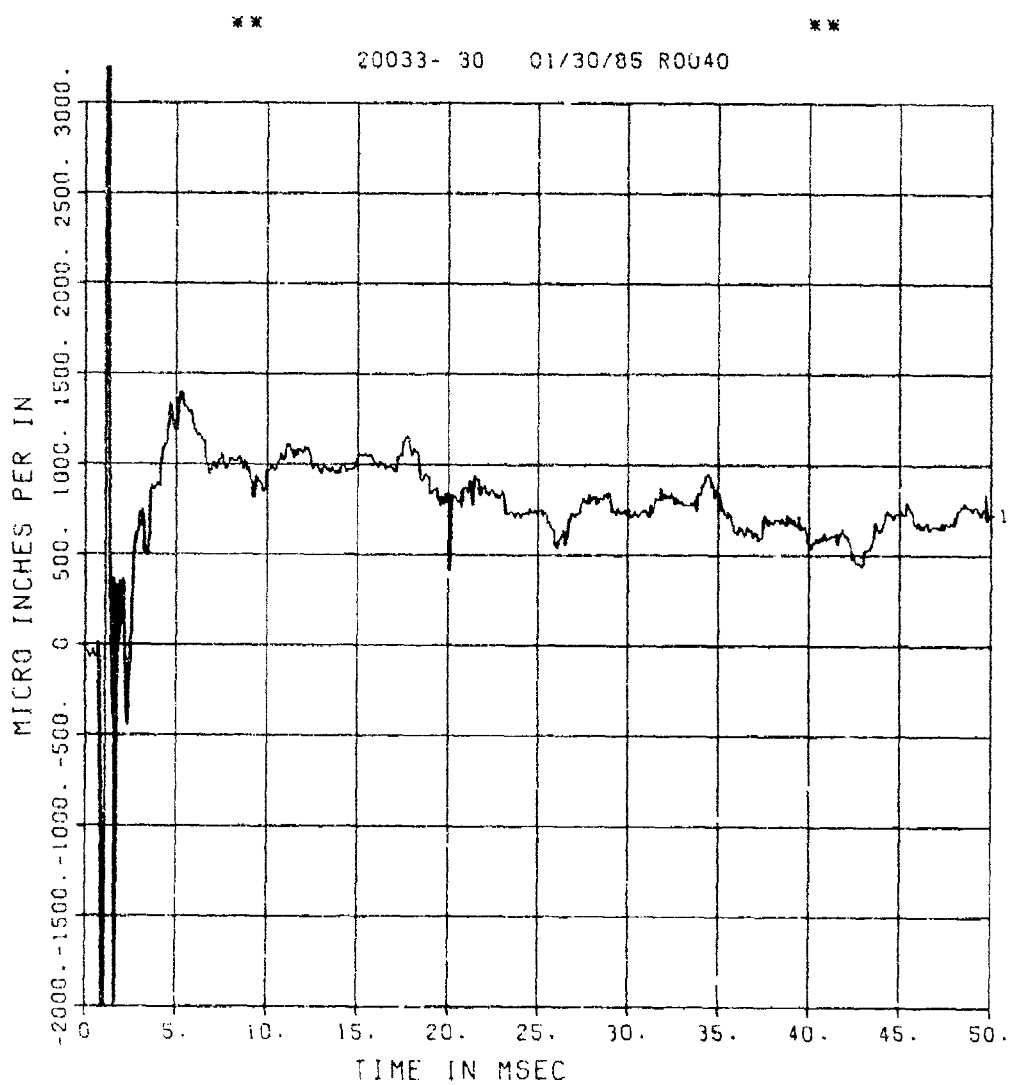


FEMA YIELD EFFECTS 2

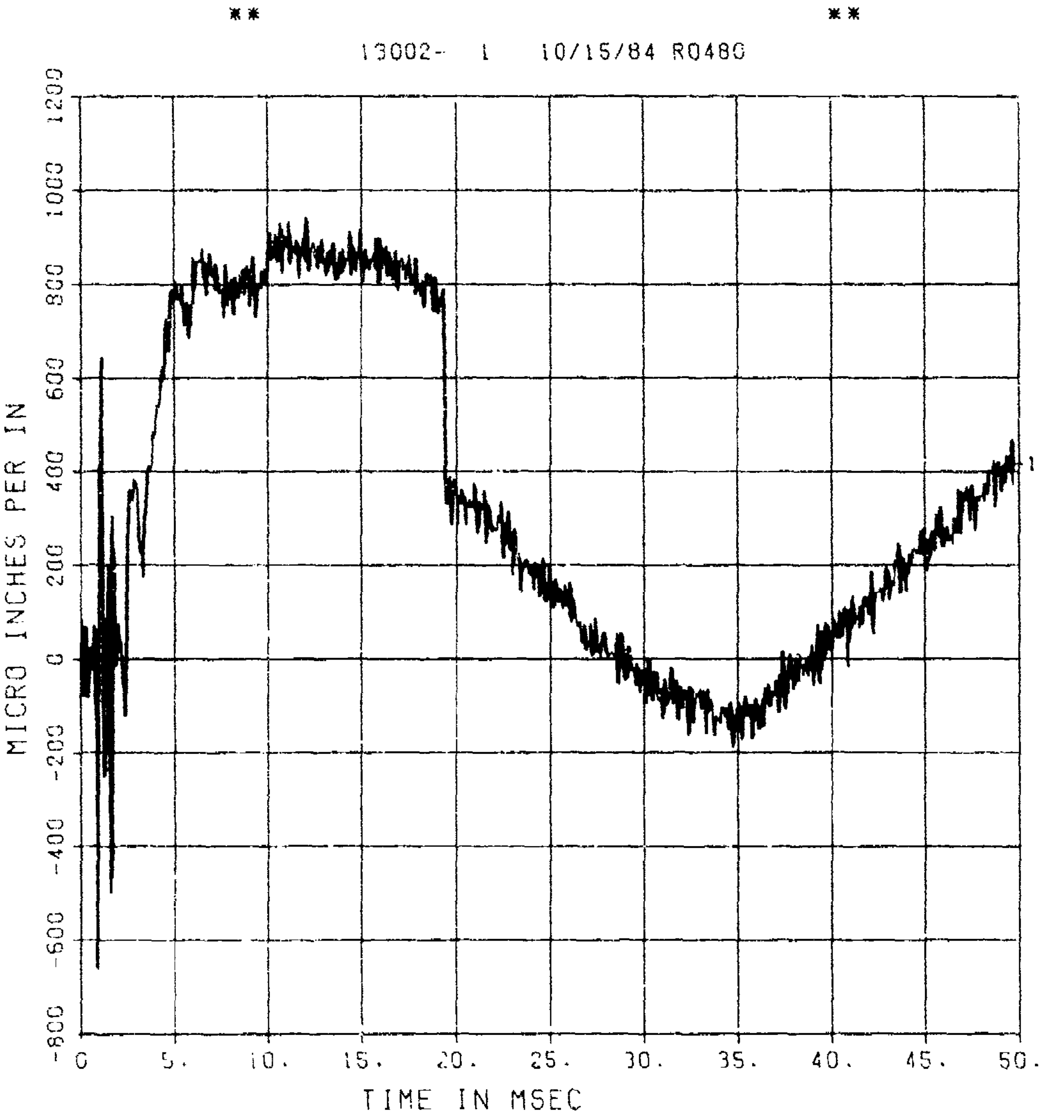
E-5

200000. HZ CAL= 9975.

LP4/0 70% CUTOFF= 9000. HZ



FEMA YIELD EFFECTS 2
E-6
200000. HZ CAL= 19613.
LP4/4 70% CUTOFF= 9000. HZ

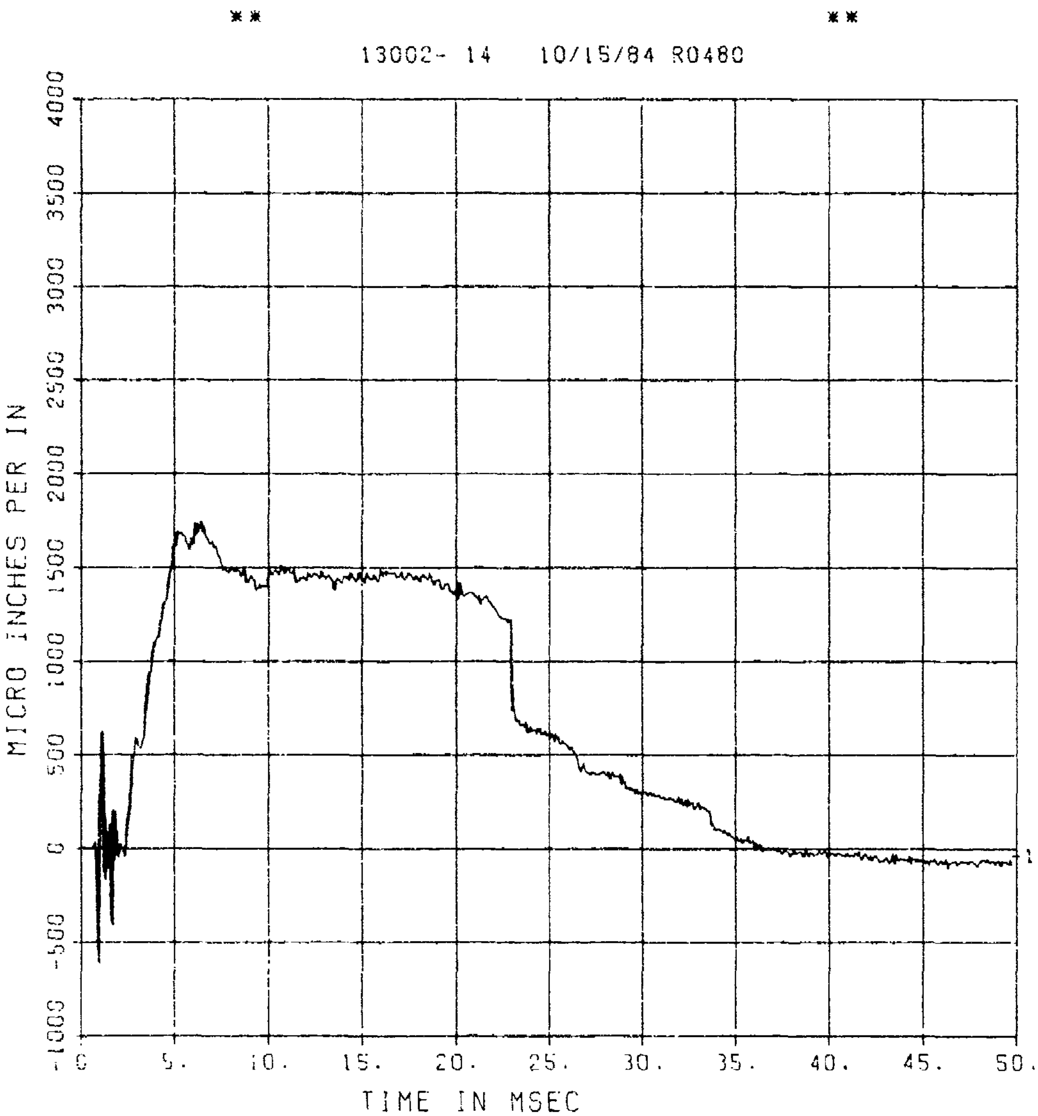


FEMA YIELD EFFECTS 2

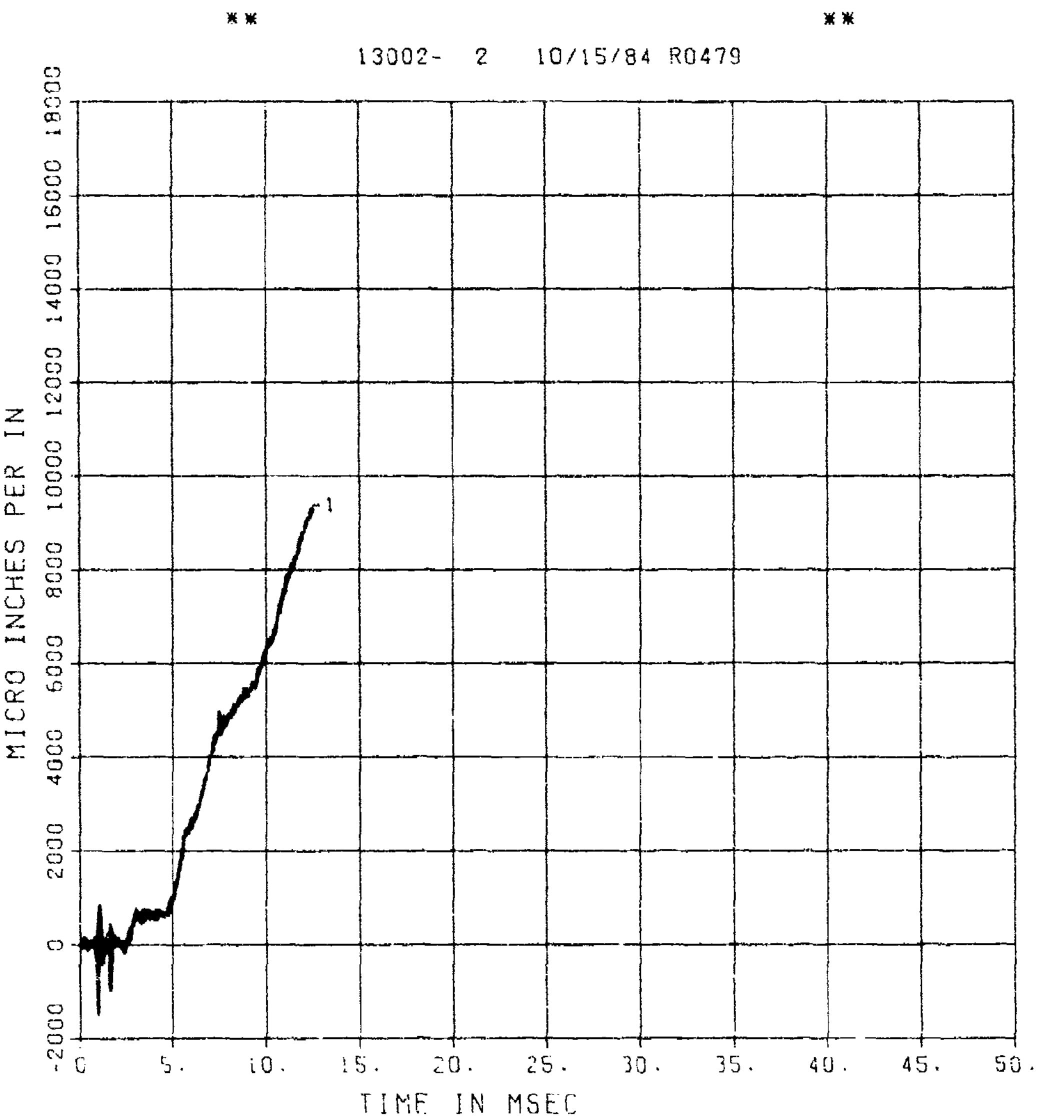
E-7A

200000. HZ   CAL= 6667.

LP2/4 70% CUTOFF= 9000. HZ



FEMA YIELD EFFECTS 2
E-8
200000. HZ CAL= 19613.

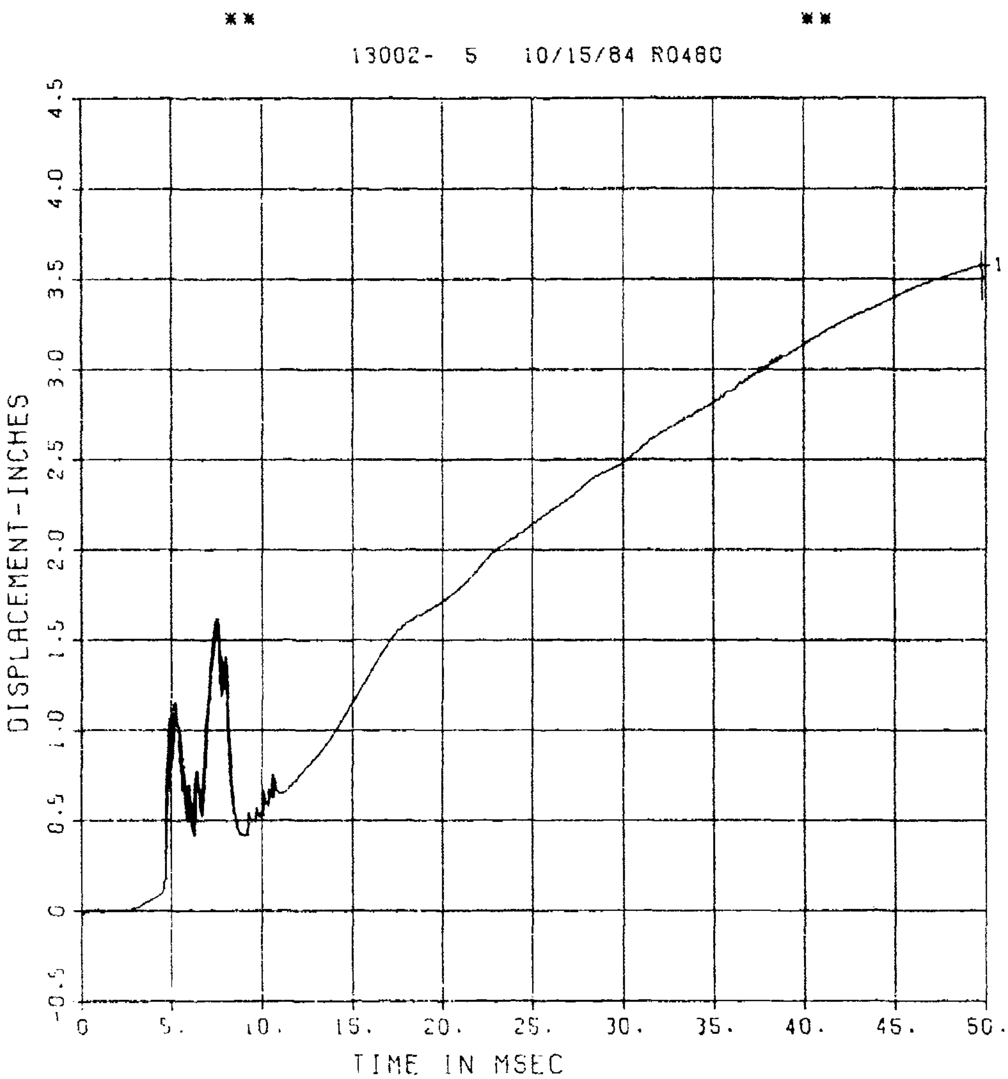


FEMA YIELD EFFECTS 2

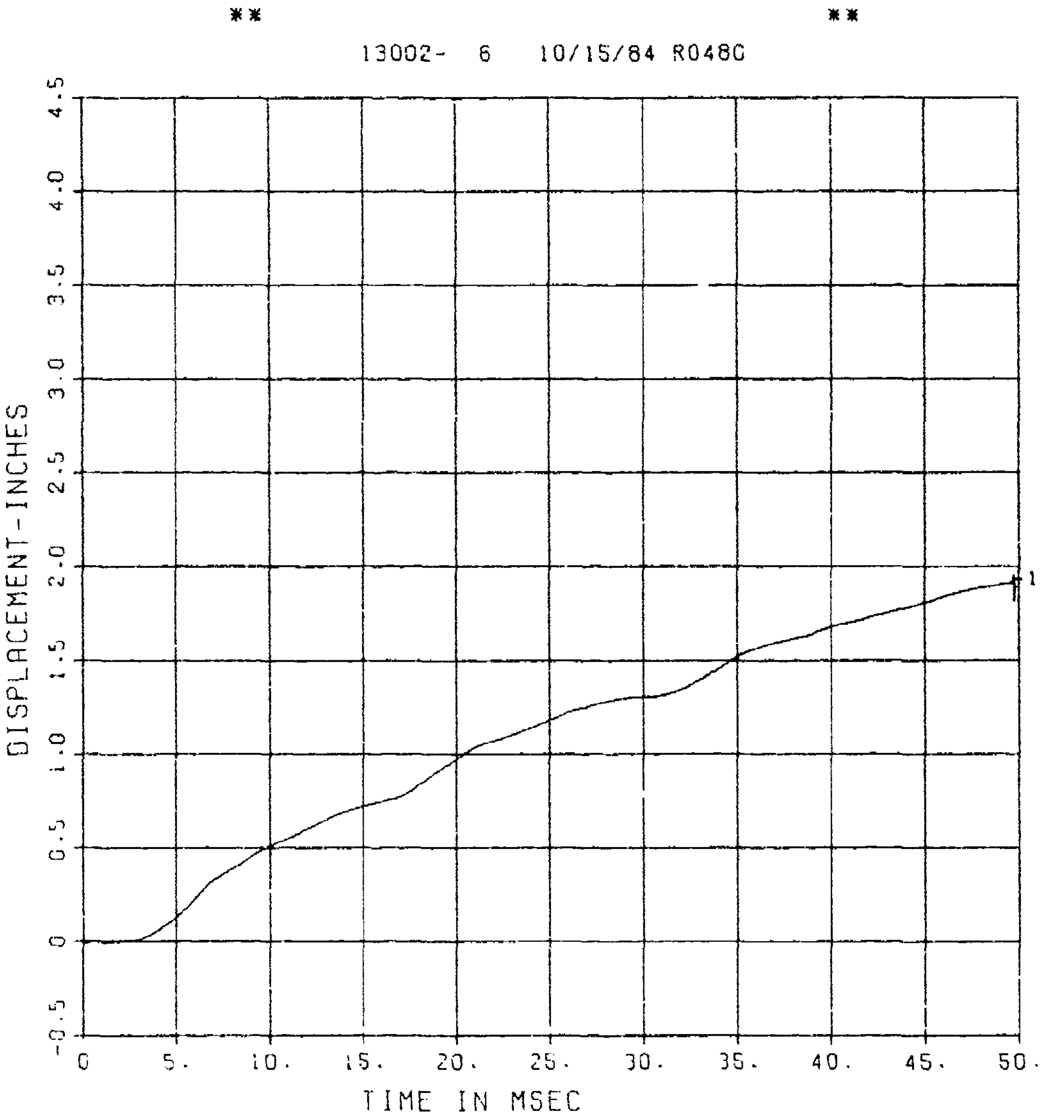
D-1

200000. HZ CAL= 2.150

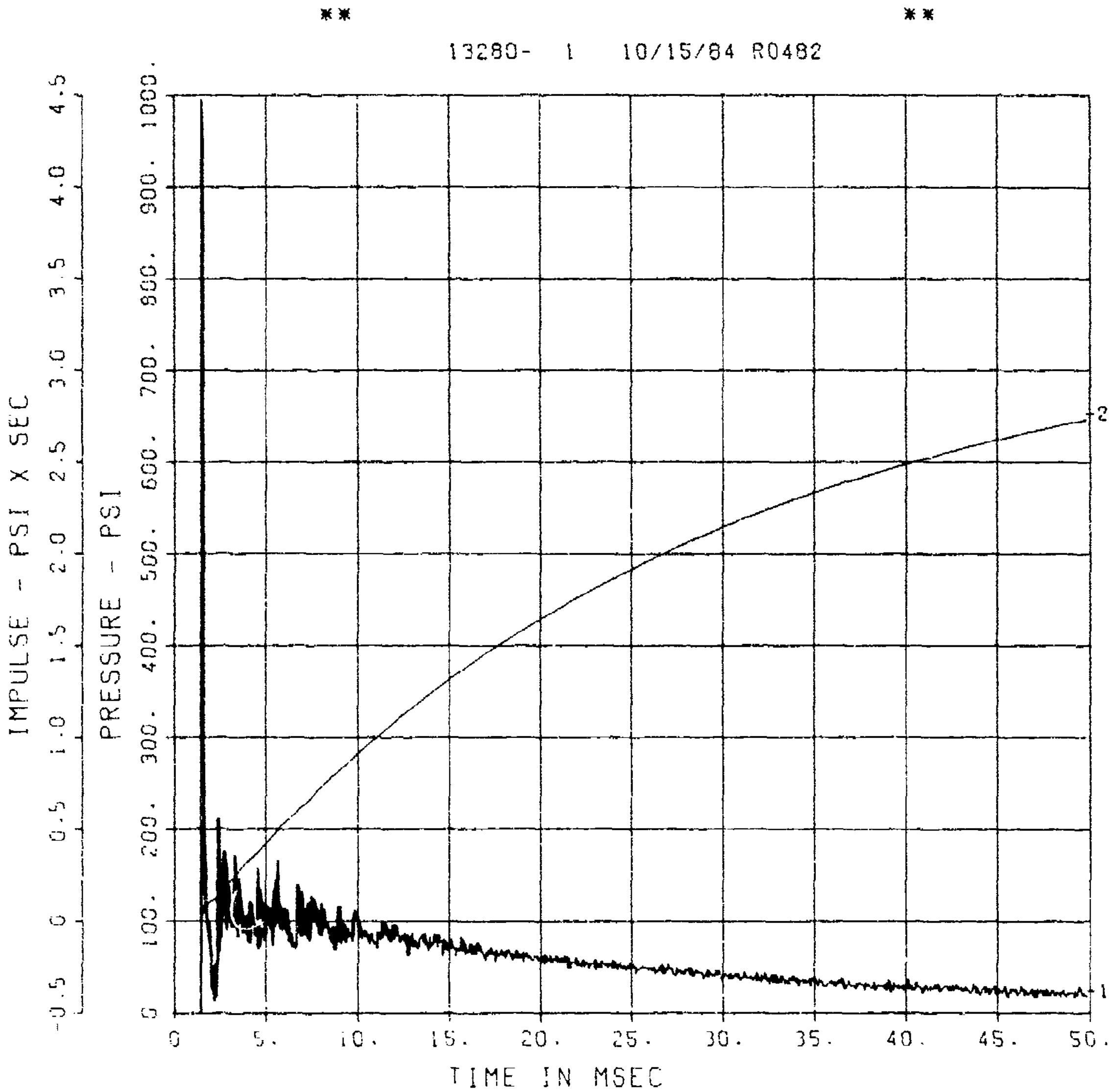
LP2/0 70% CUTOFF= 18000. HZ



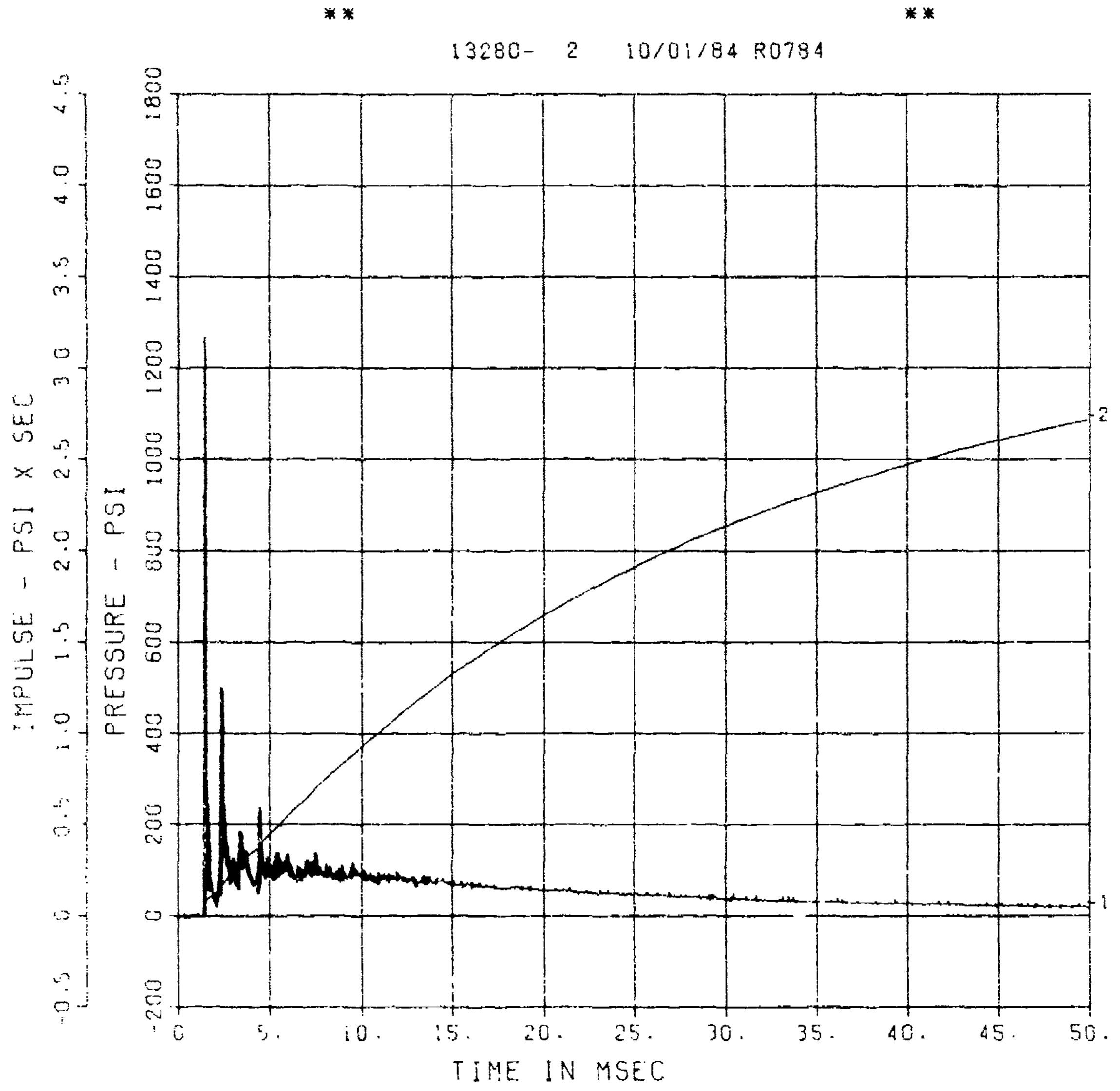
FEMA YIELD EFFECTS 2
D-2
200000. HZ CAL= 1.080
LP2/0 70% CUTOFF= 18000. HZ



FEMA YIELD EFFECTS 3
BP-1
200000. HZ CAL= 1314.
LP2/0 70% CUTOFF= 18000. HZ



FEMA YIELD EFFECTS 3
BP-2
200000. HZ CAL= 952.0



FEMA YIELD EFFECTS 3

BP-3

00000. HZ CAL= 932.0

LP2/0 70% CUTOFF= 18000. HZ

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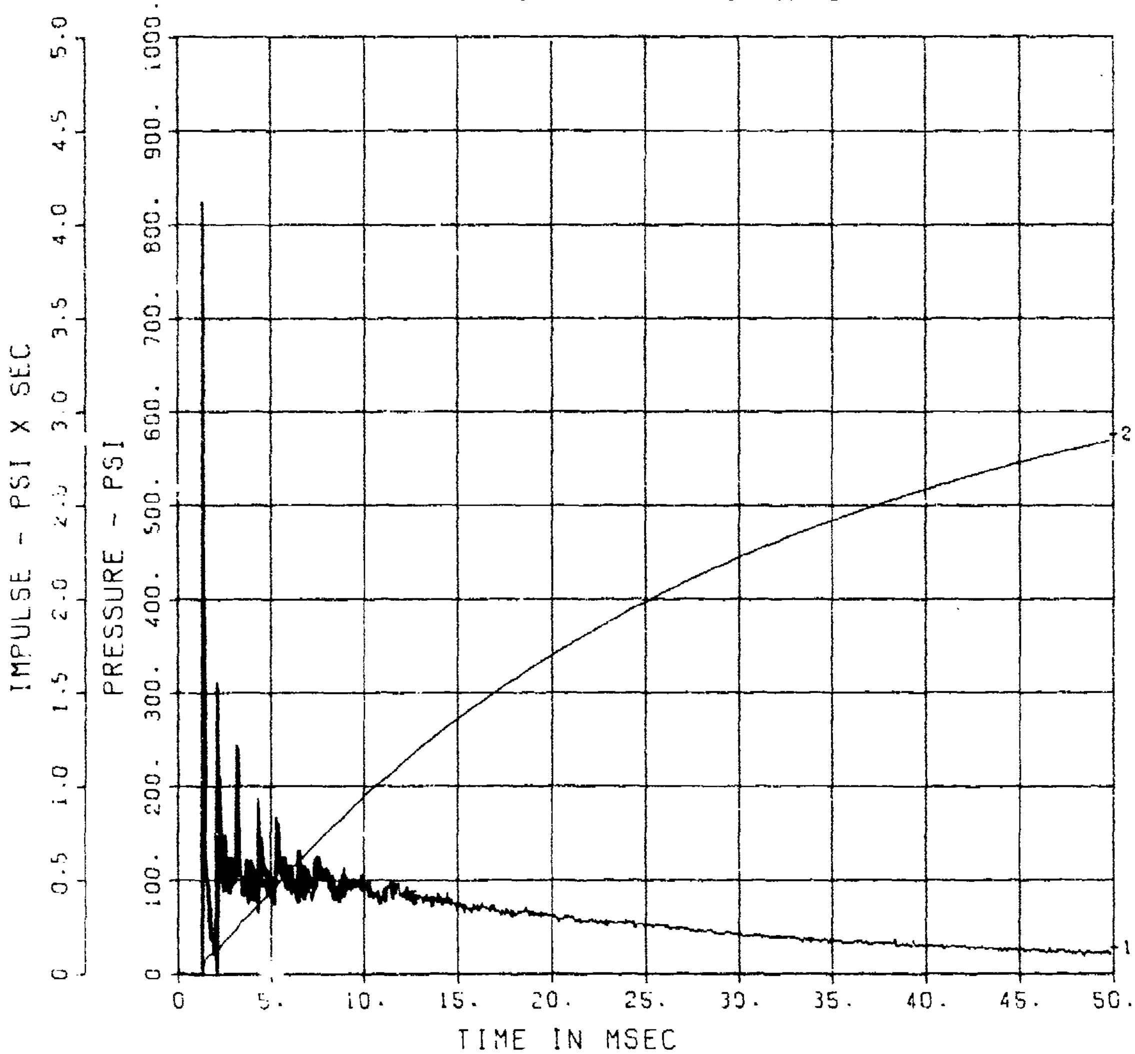
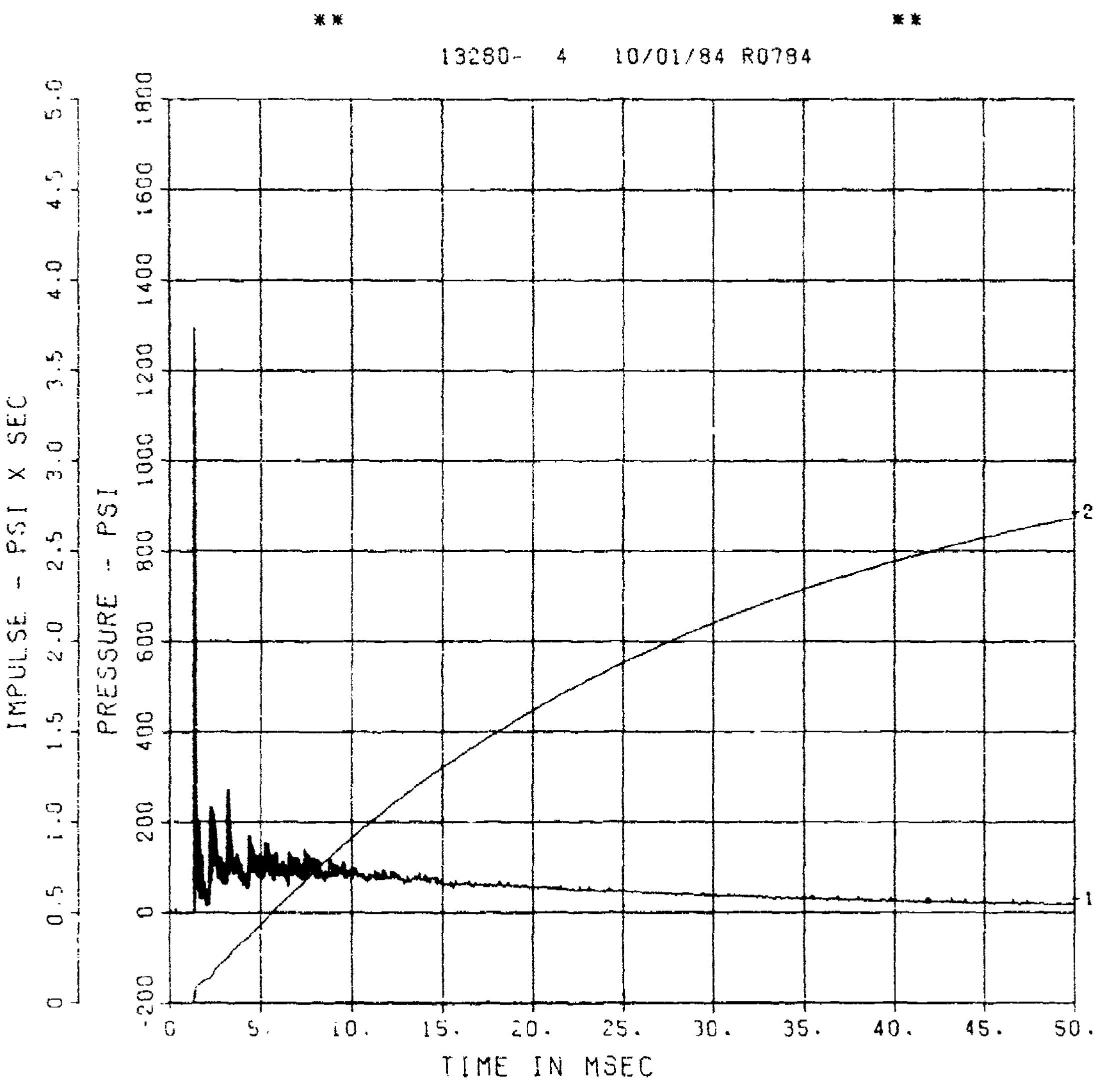
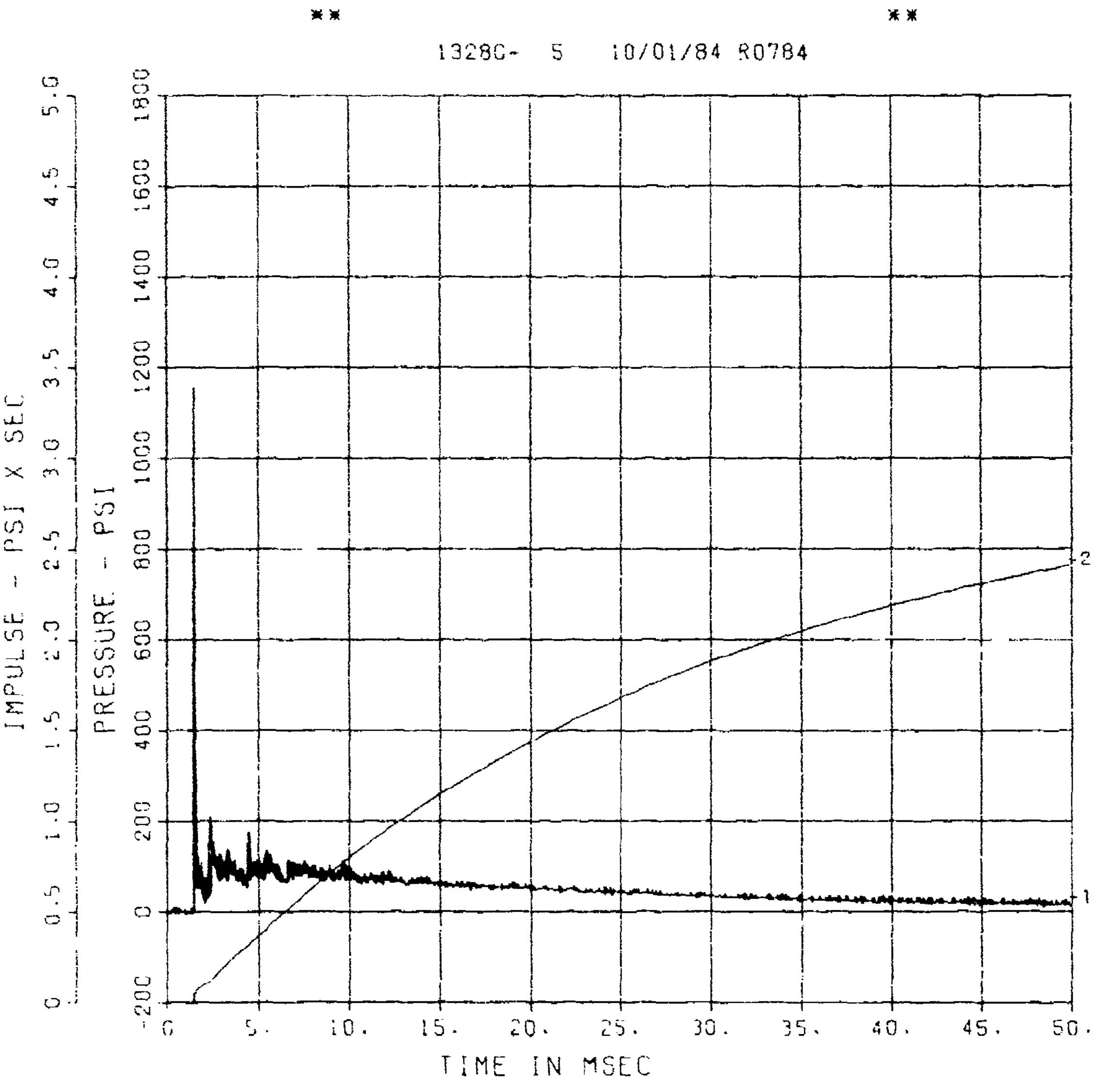
13280- 3 10/15/84 R0482



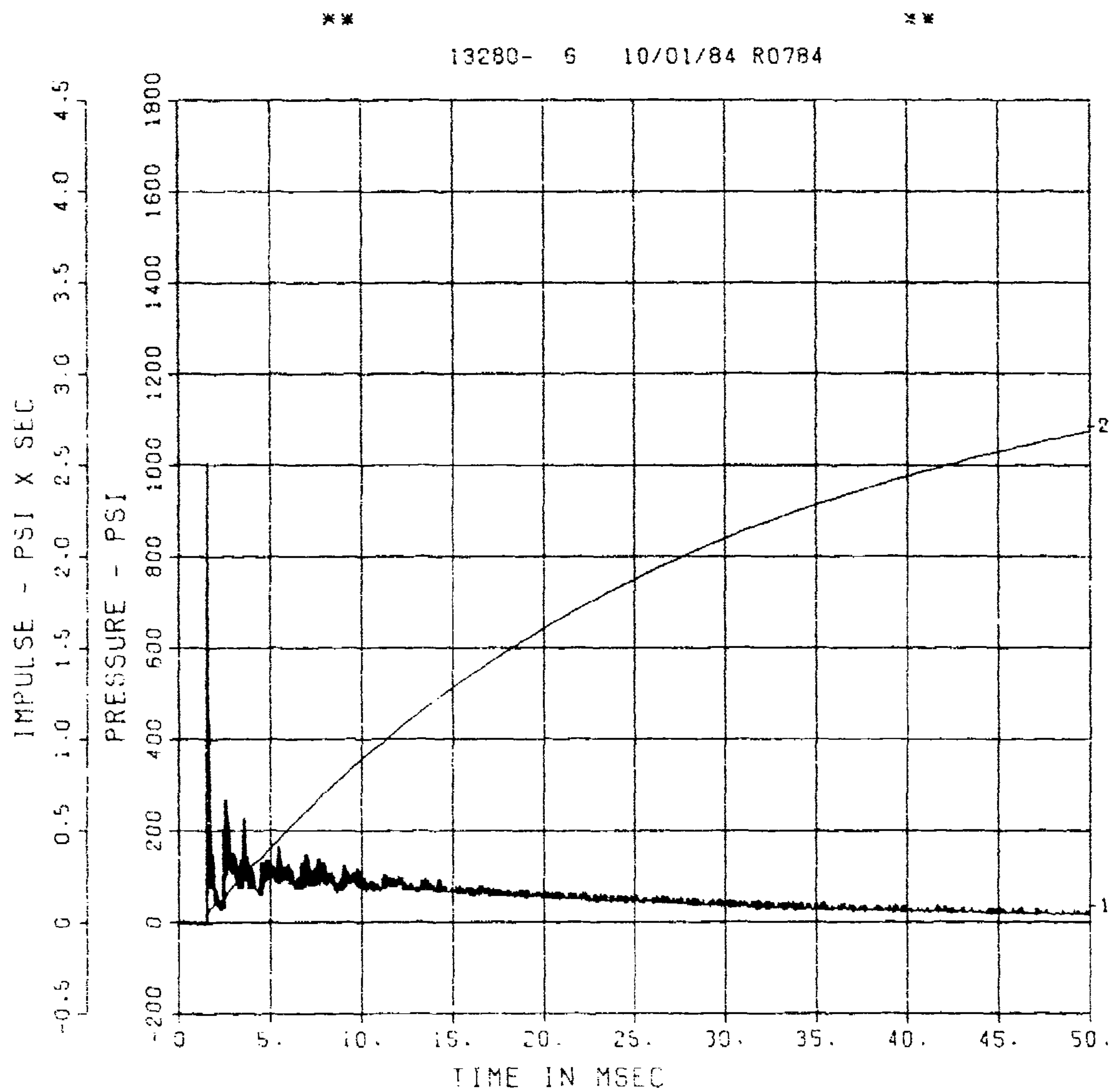
FEMA YIELD EFFECTS 3
BP-4
200000. HZ CAL= 864.0



FEMA YIELD EFFECTS 3
BP-5
200000. HZ CAL= 1152.



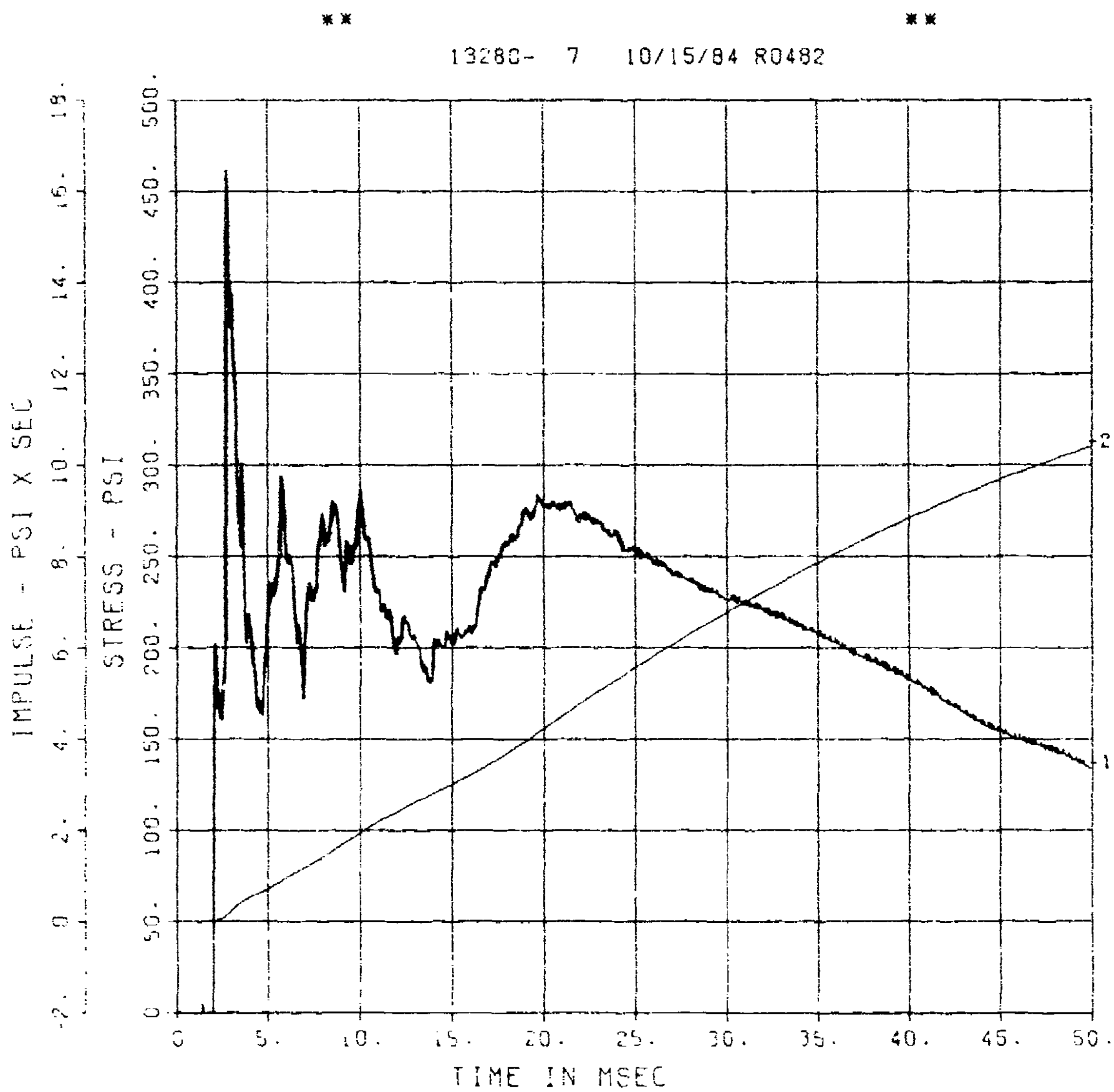
FEMA YIELD EFFECTS 3
BP-6
200000. HZ CAL= 1118.



FEMA YIELD EFFECTS 3

SE-1

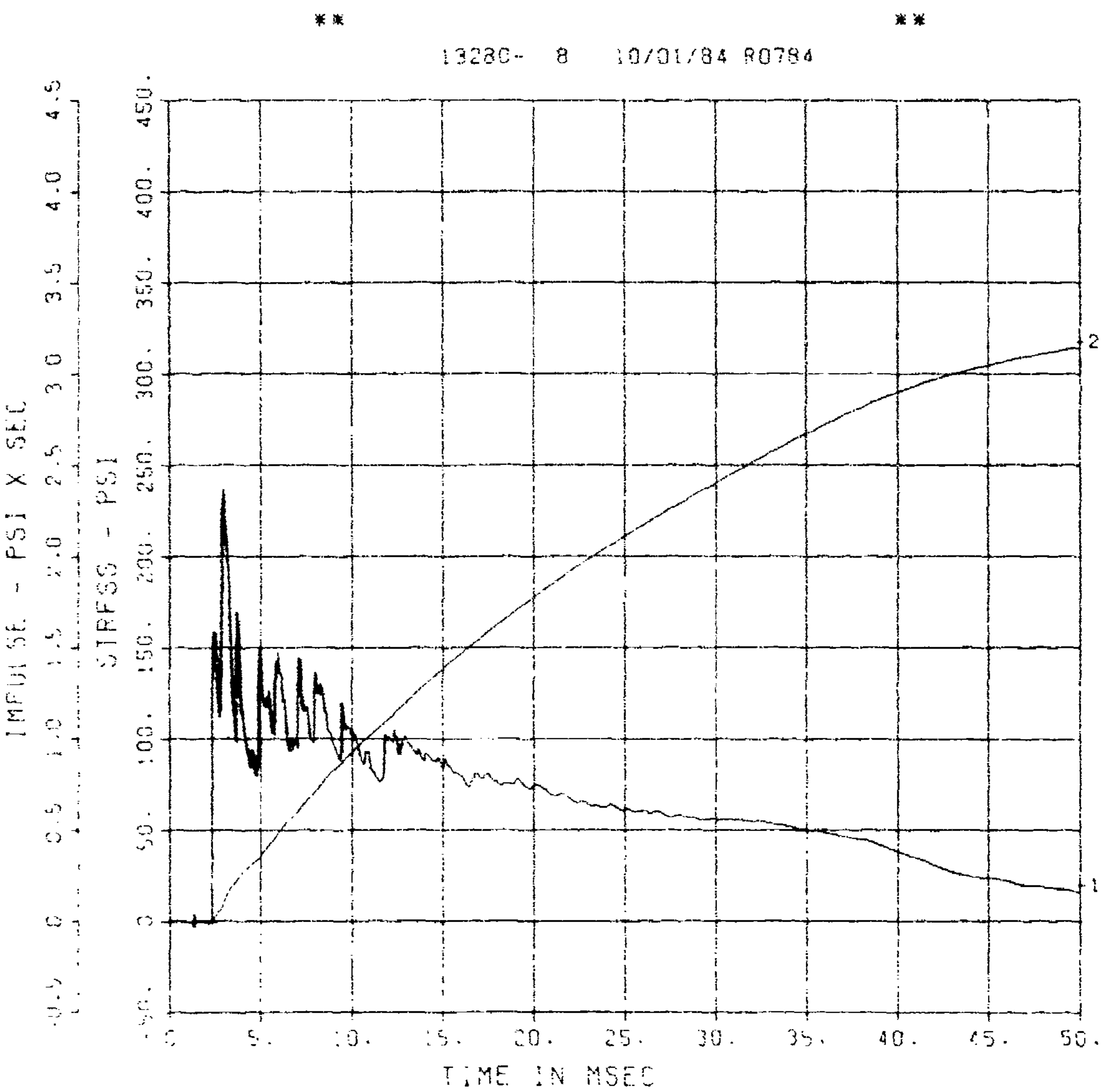
200000. HZ CAL= 294.0



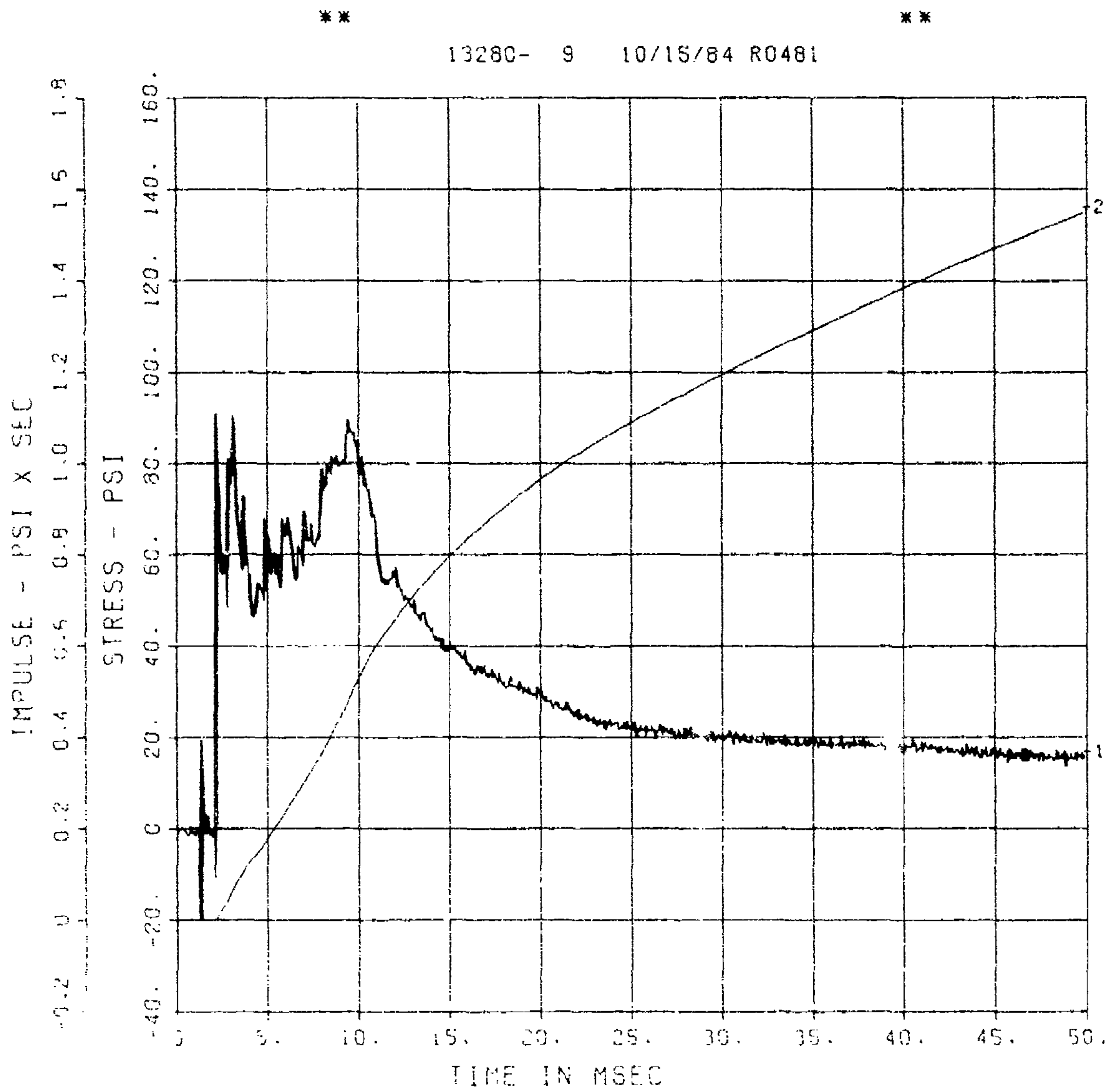
FEMA YIELD EFFECTS 3

SE-2

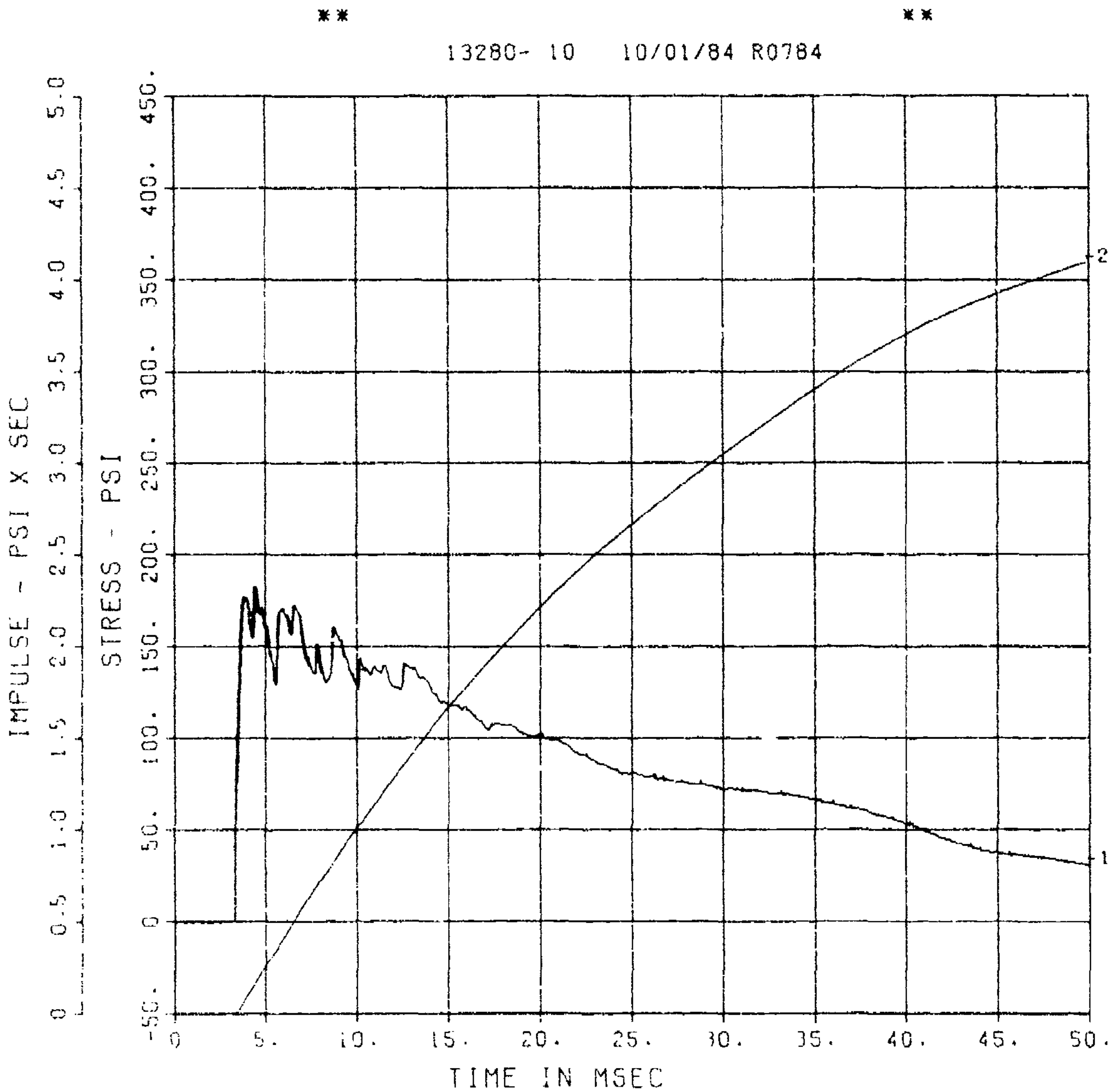
200000. HZ CAL= 115.0



FEMA YIELD EFFECTS 3
SE-3
200000. HZ CAL= 310.0
LP2/0 70% CUTOFF= 18000. HZ



FEMA YIELD EFFECTS 3
SE-4
200000. HZ CAL= 183.0

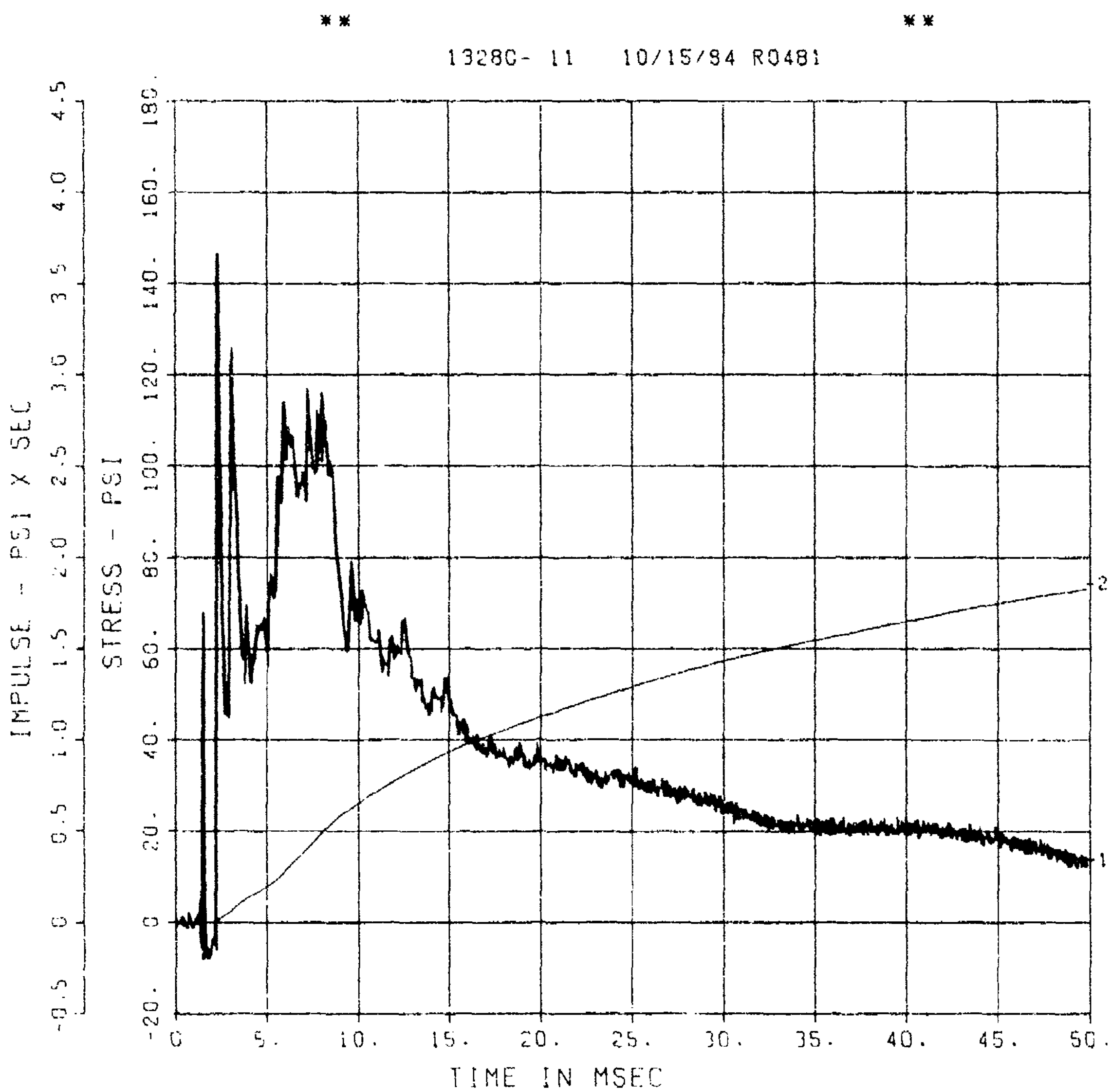


FEMA YIELD EFFECTS 3

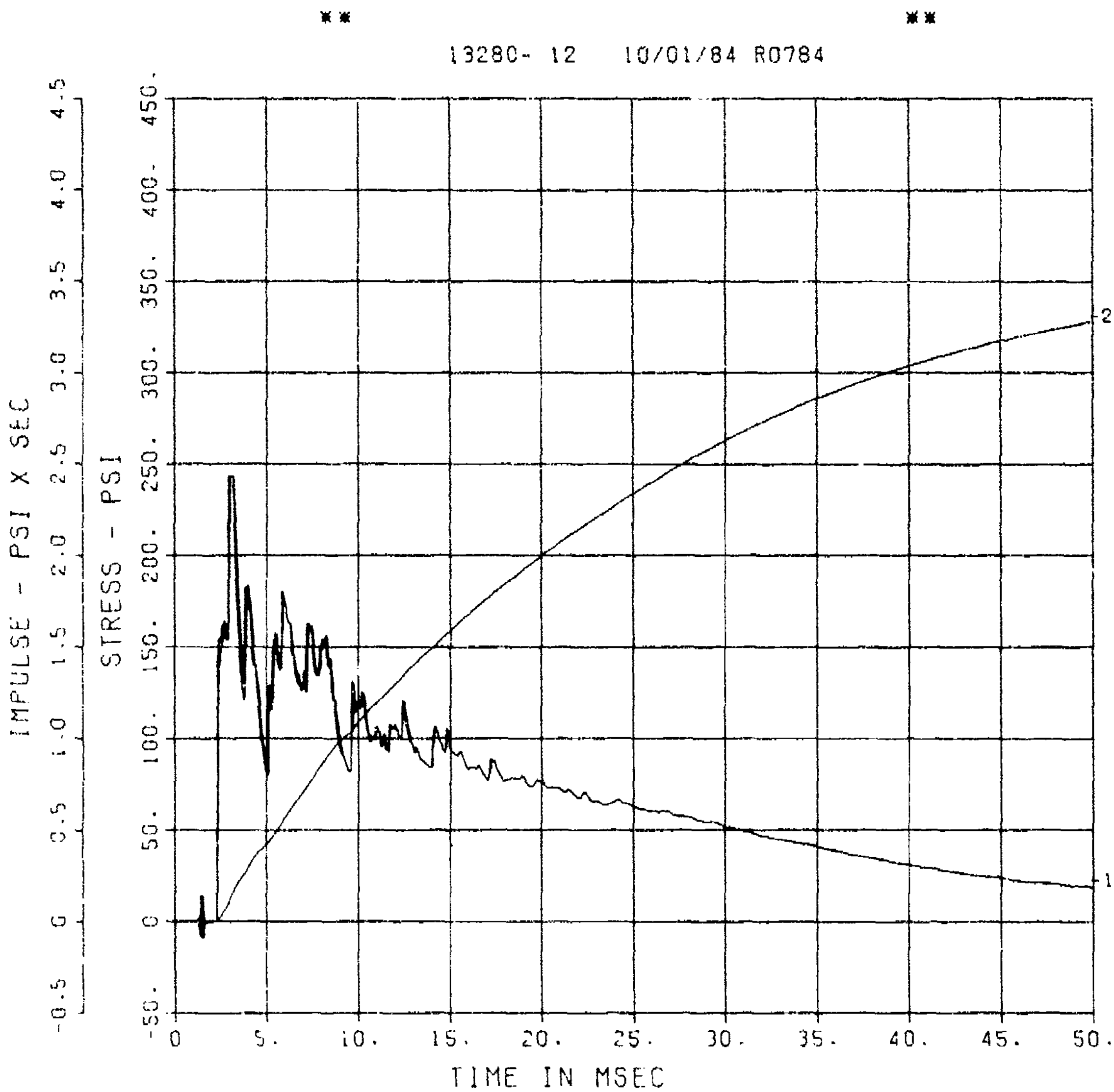
SE-5

200000. HZ CAL= 396.0

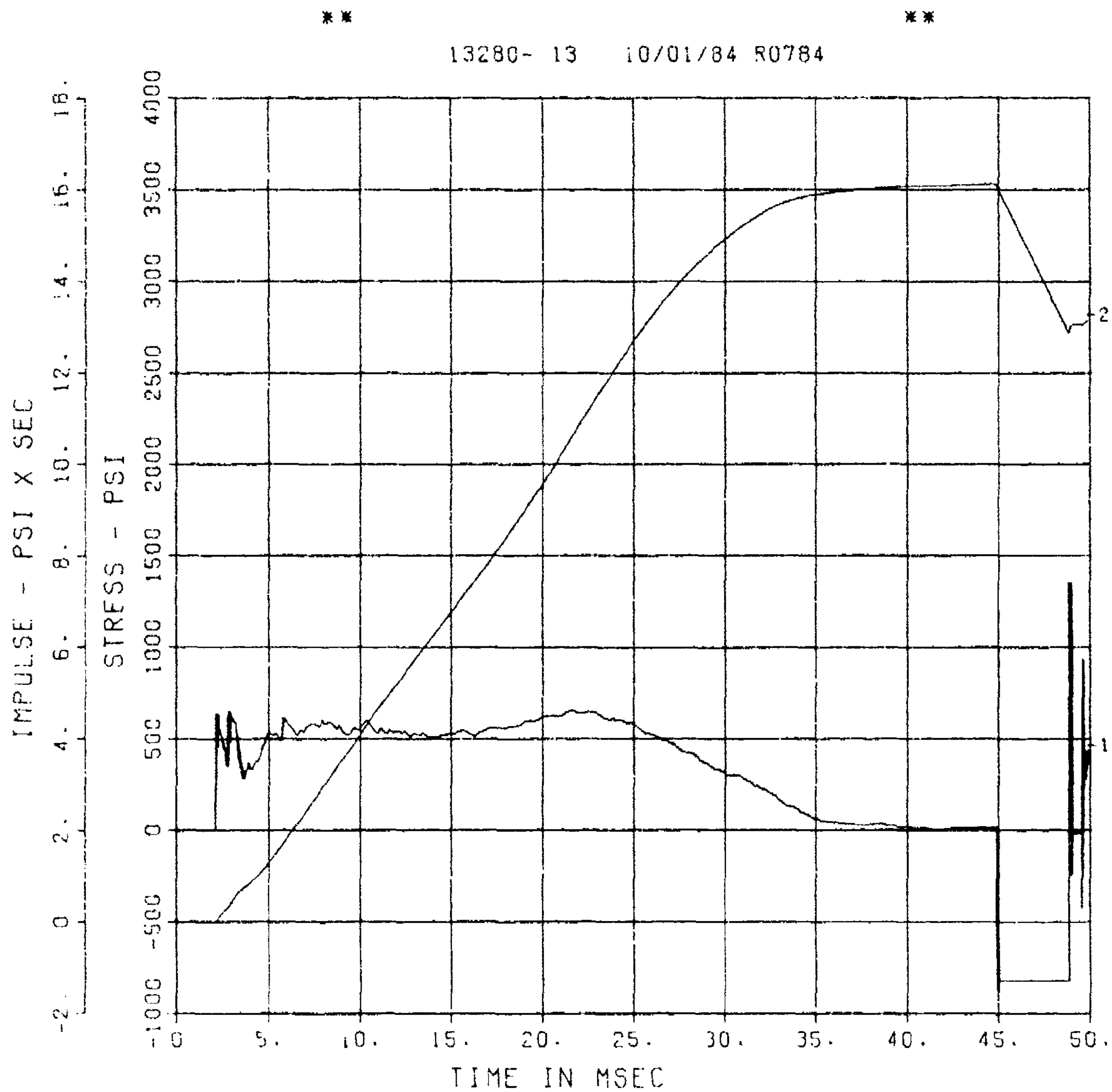
LP2/0 70% CUTOFF= 18000. HZ



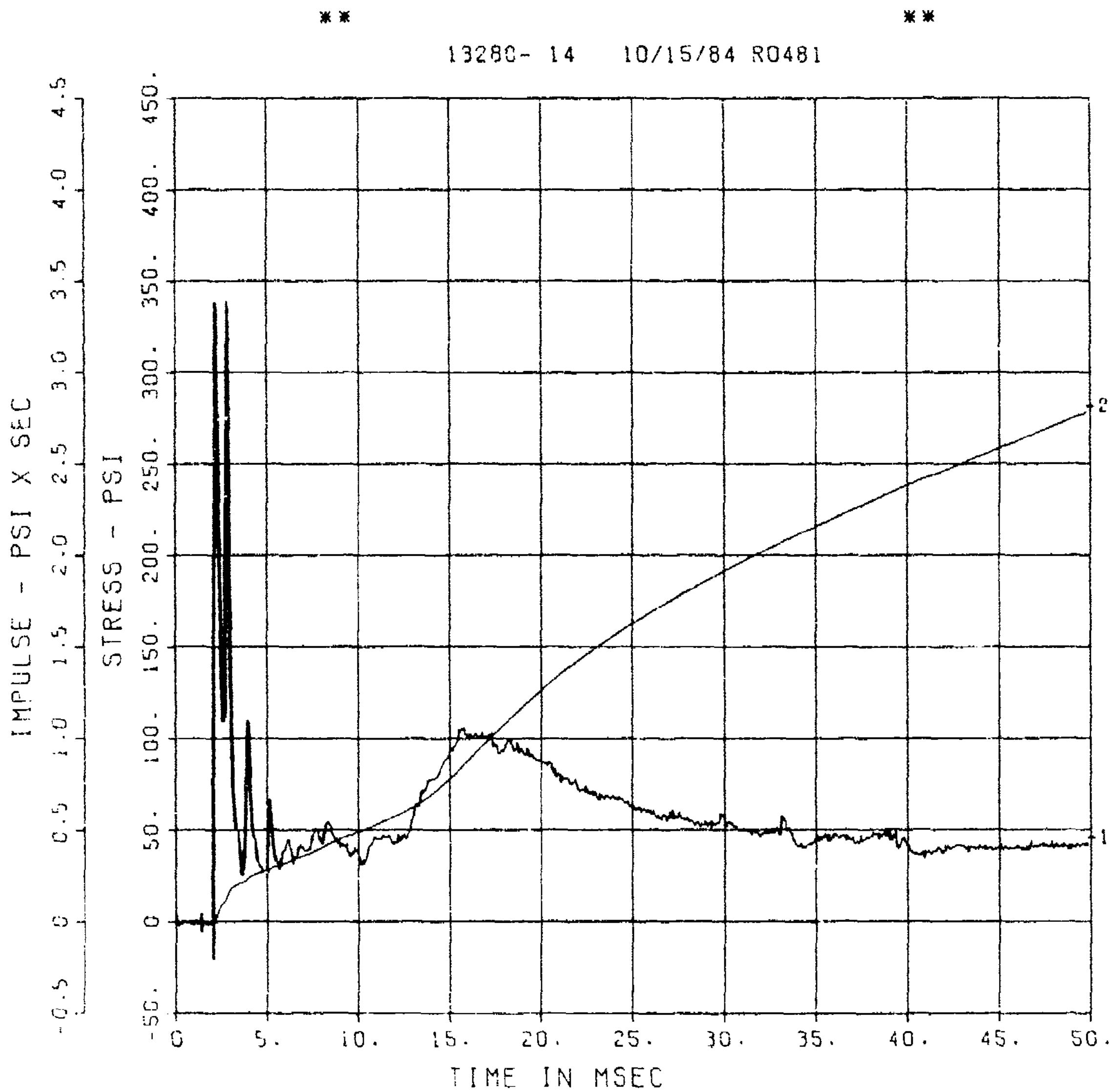
FEMA YIELD EFFECTS 3
SE-6
200000. HZ CAL= 125.0



FEMA YIELD EFFECTS 3
SE-7
200000. HZ CAL= 671.0



FEMA YIELD EFFECTS 3
SE-8
200000. HZ CAL= 560.0
LP2/0 70% CUTOFF= 18000. HZ



FEMA YIELD EFFECTS 3

SE-9

200000. HZ CAL= 269.0

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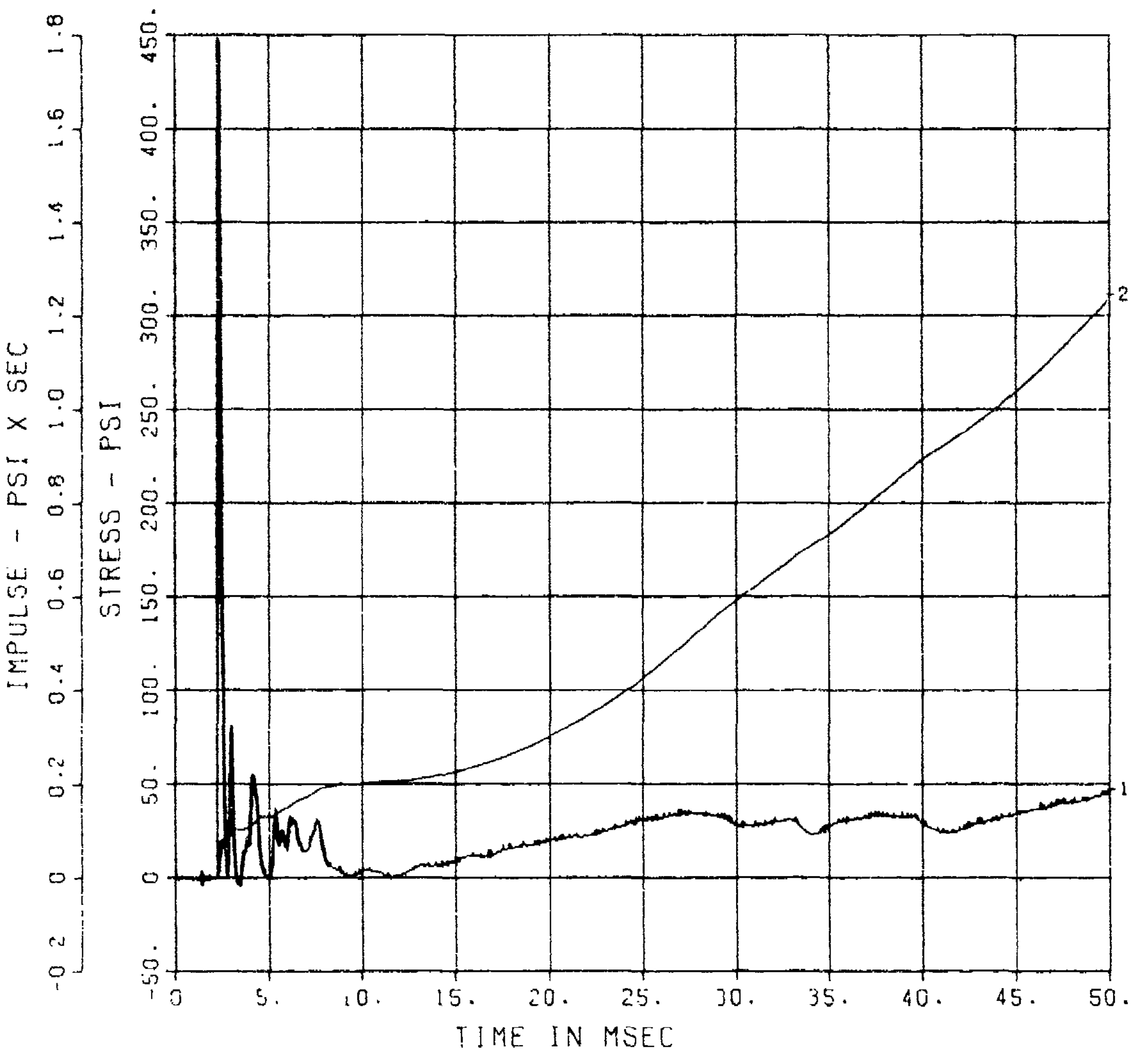
13280- 15 10/01/84 R0784

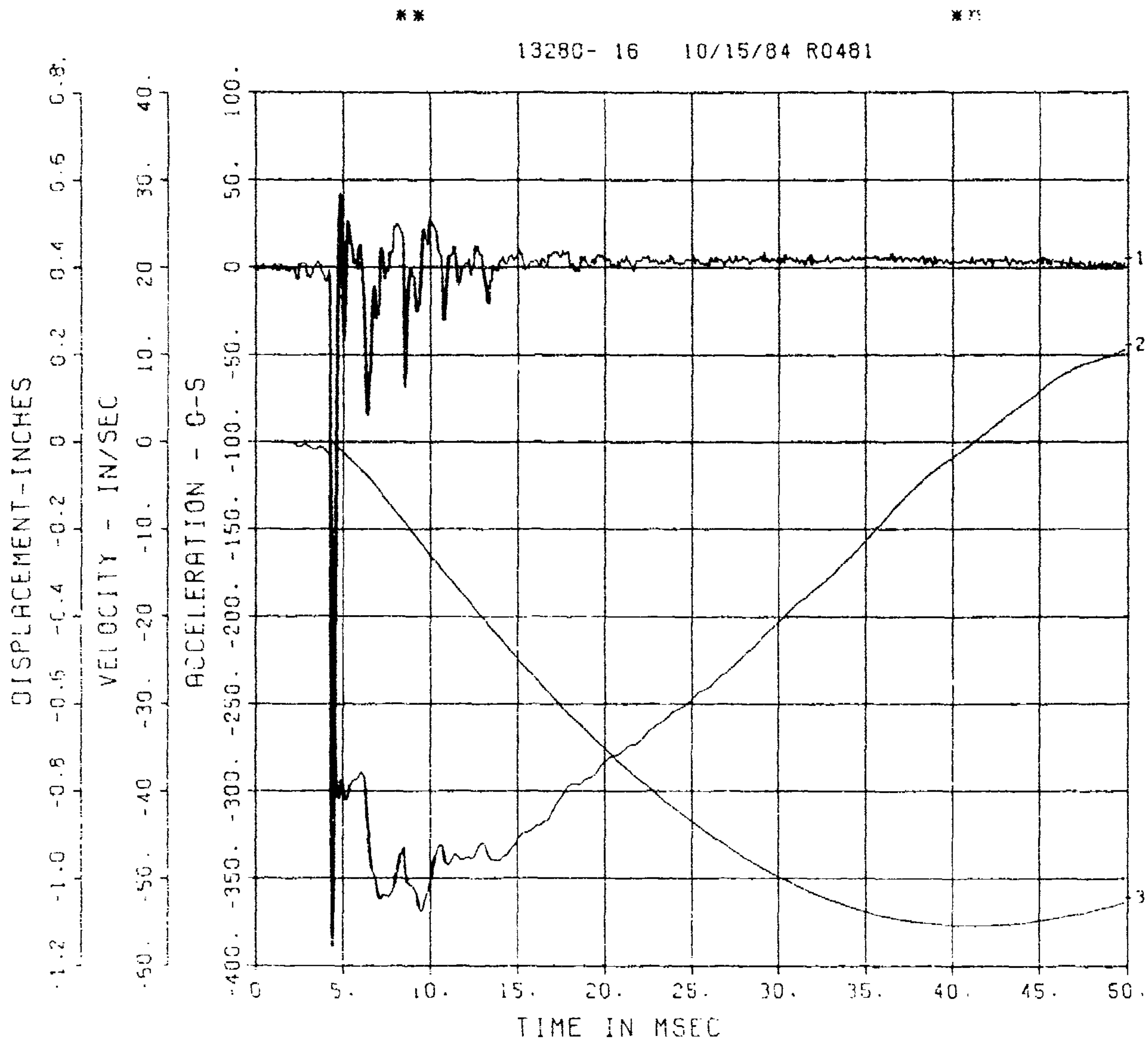


FEMA YIELD EFFECTS 3

AFF-1

200000. HZ CAL= 836.0

LP4/0 70% CUTOFF= 9000. HZ

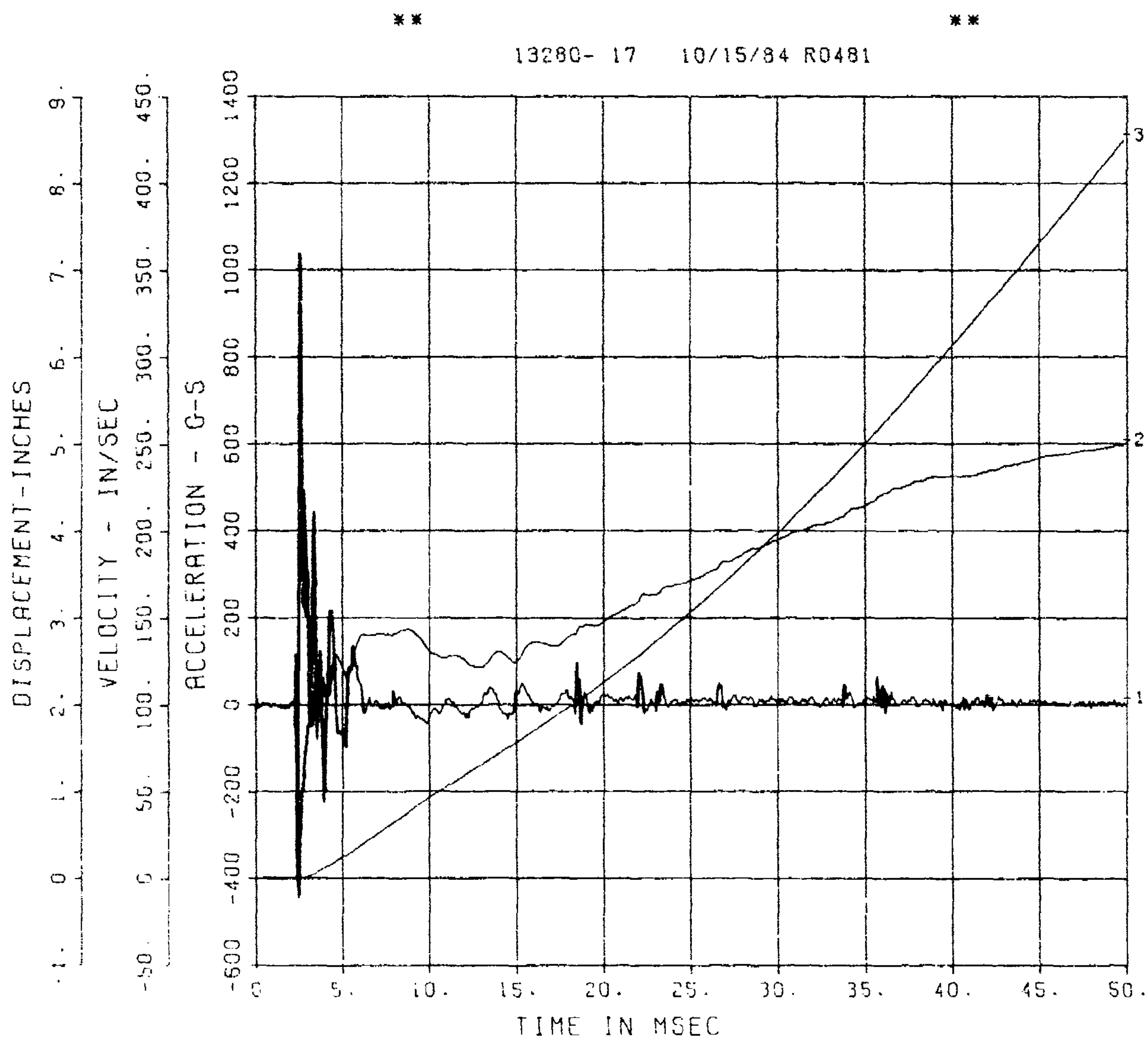


FEMA YIELD EFFECTS 3

A-1

200000. HZ   CAL= 2310.

LP4/0 70% CUTOFF= 9000. HZ

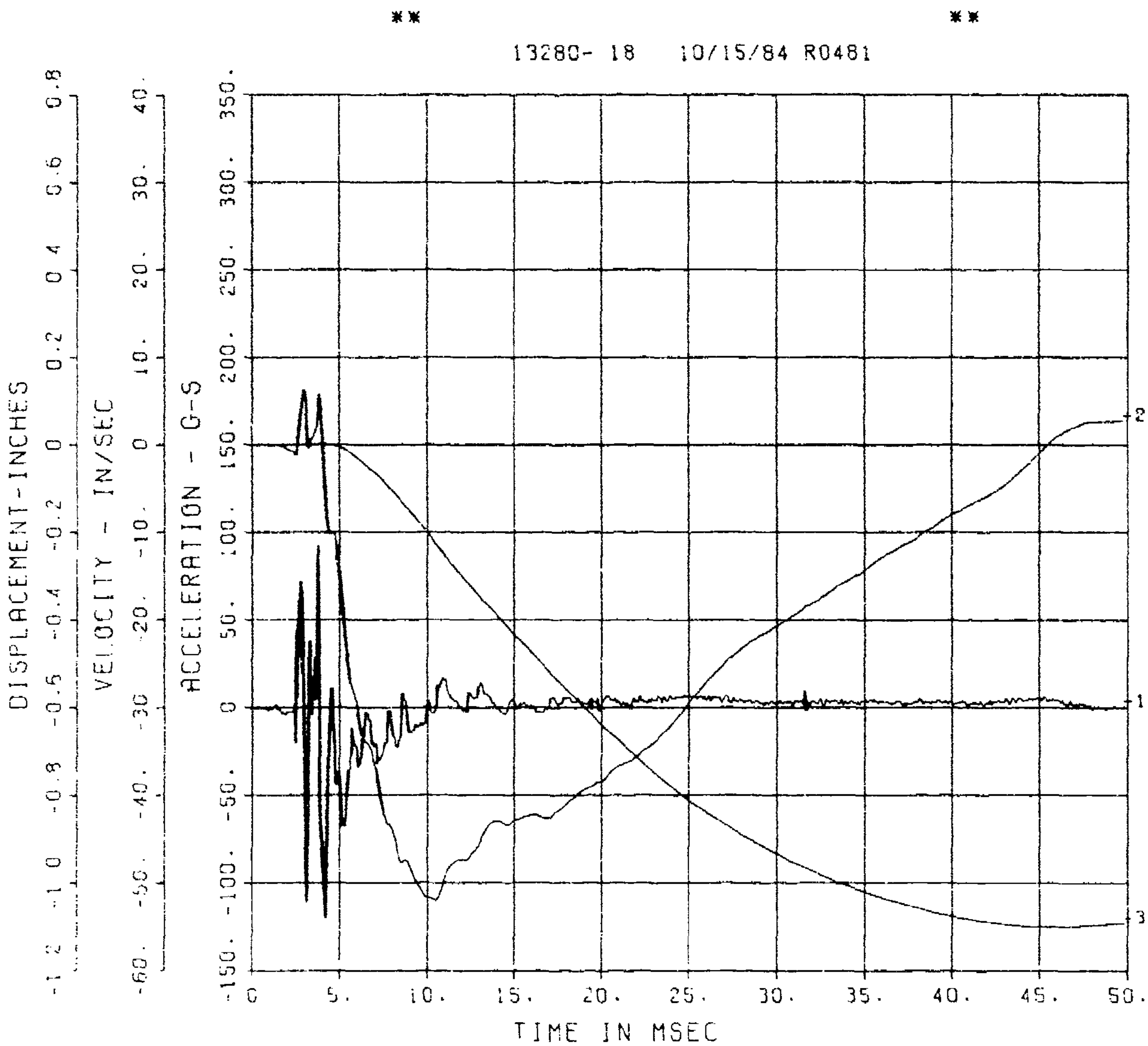


FEMA YIELD EFFECTS 3

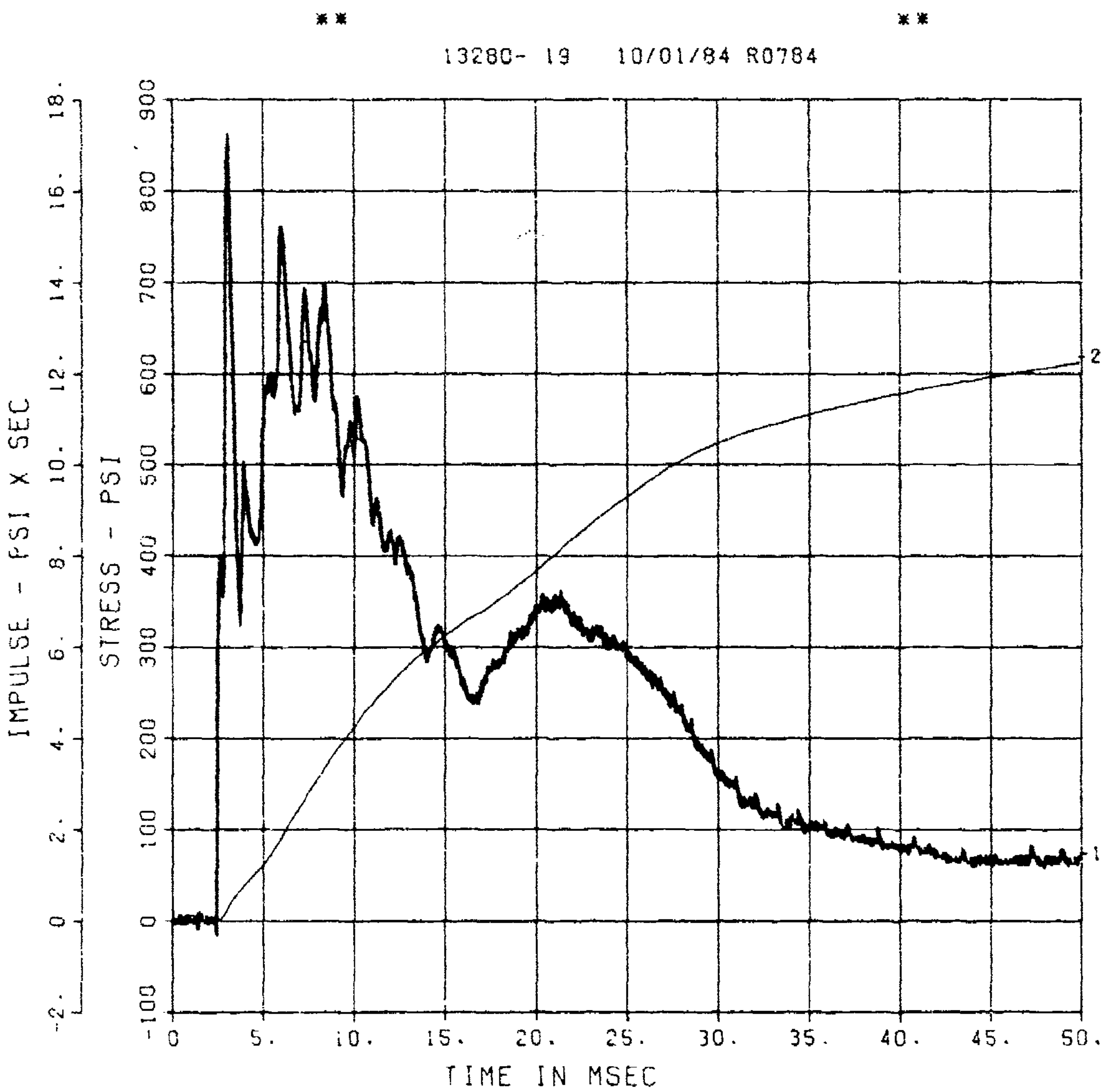
A-2

200000. HZ CAL= 474.0

LP4/0 70% CUTOFF= 9000. HZ



FEMA YIELD EFFECTS 3
IF-1
200000. HZ CAL= 631.0

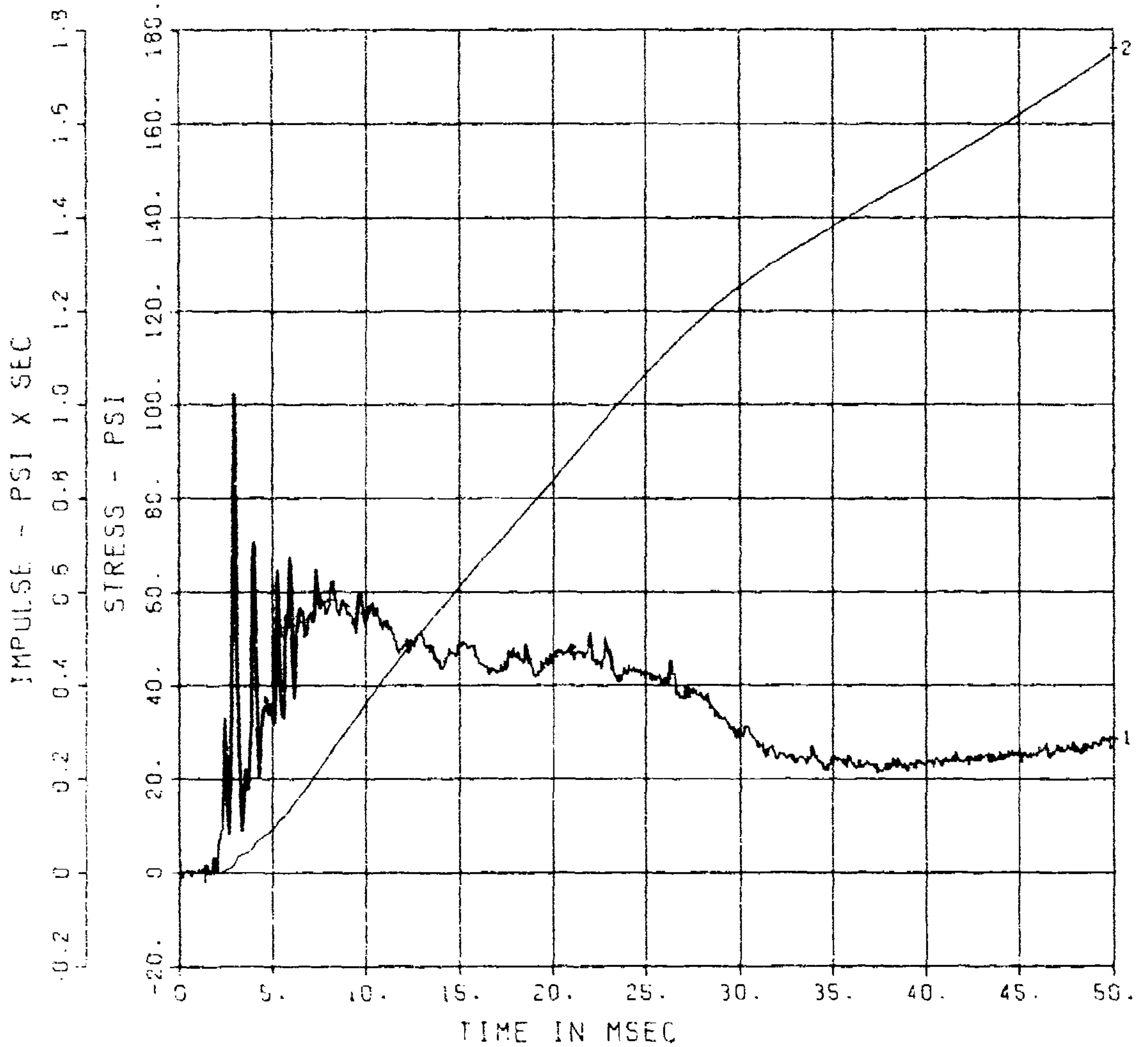


FEMA YIELD EFFECTS 3
IF-2
200000. HZ CAL= 306.0

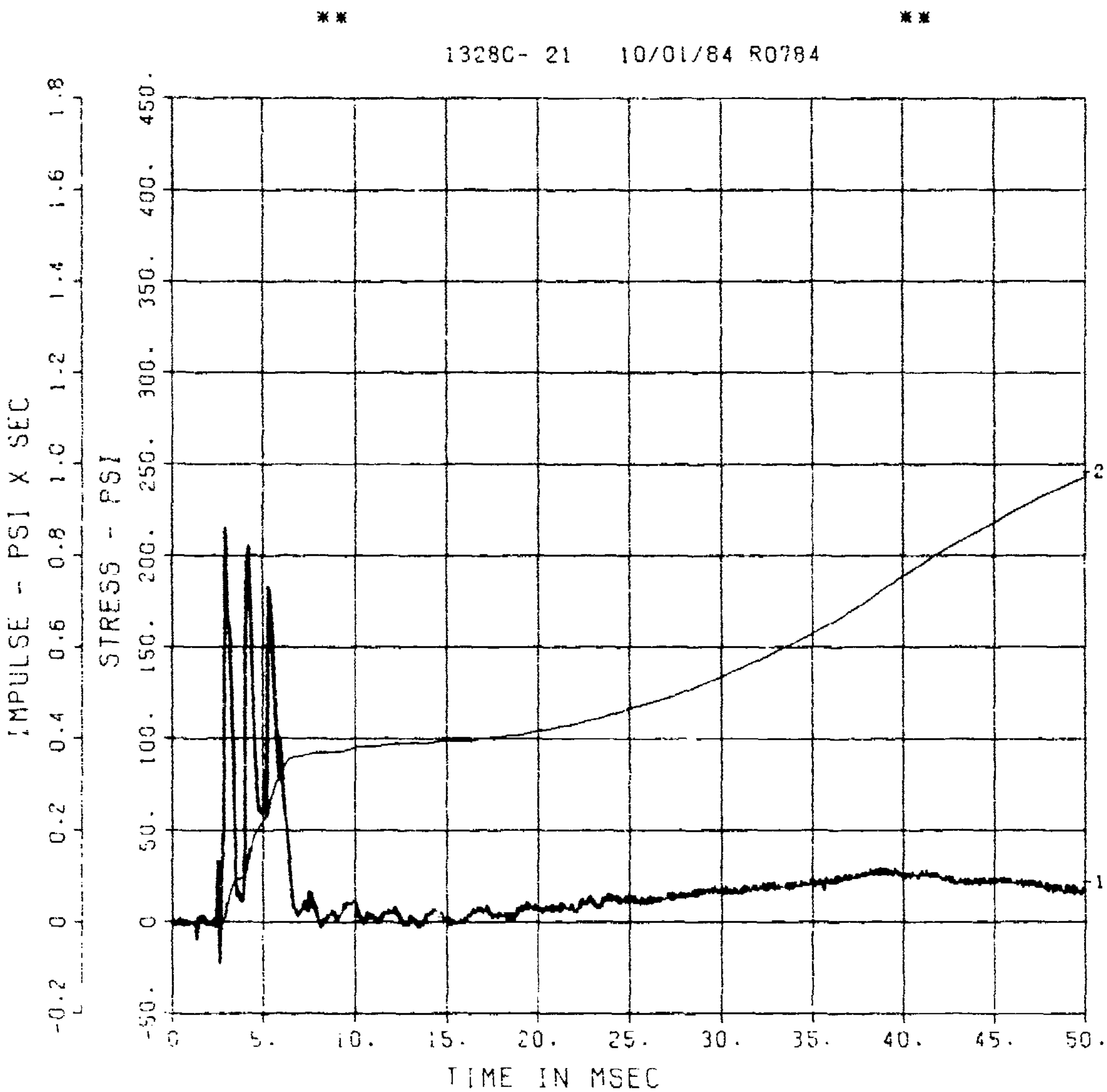
LP2/0 70% CUTOFF= 18000. HZ

** **

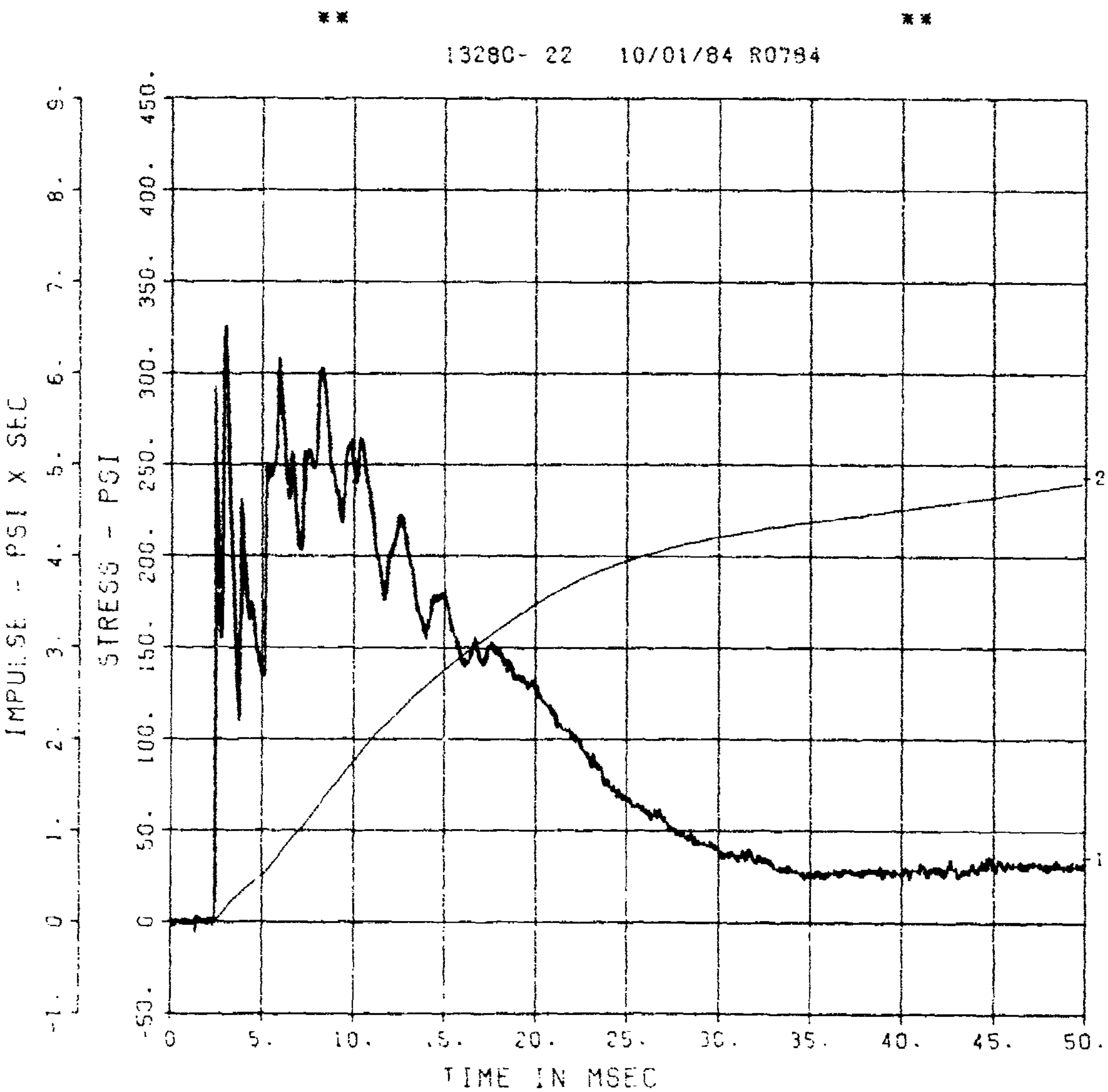
13280- 20 10/15/84 R0481



FEMA YIELD EFFECTS 3
IF-3
200000. HZ CAL= 298.0



FEMA YIELD EFFECTS 3
IF-4
200000. HZ CAL= 304.0



FEMA YIELD EFFECTS 3

IF-5

200000. HZ CAL= 124.0

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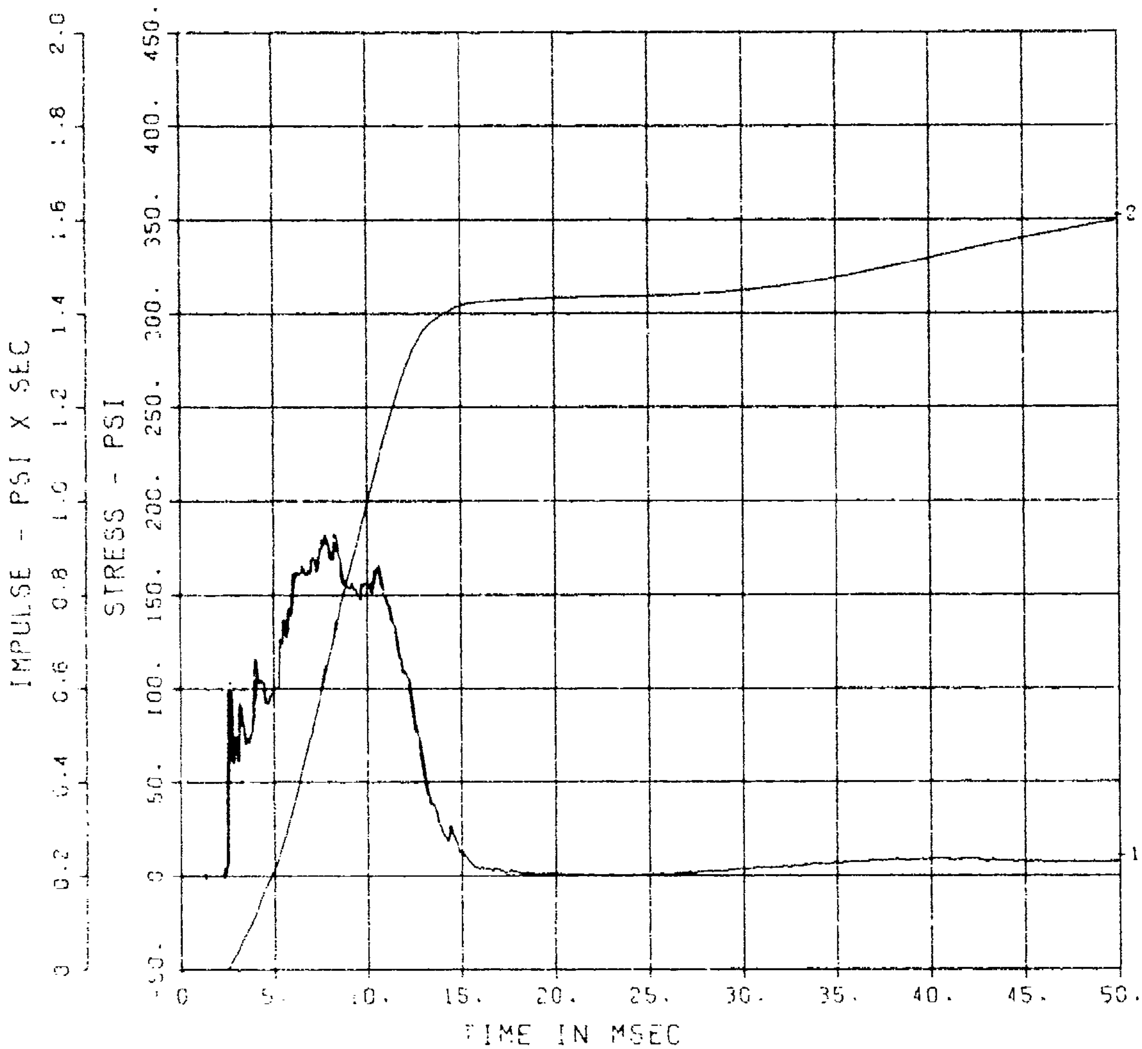
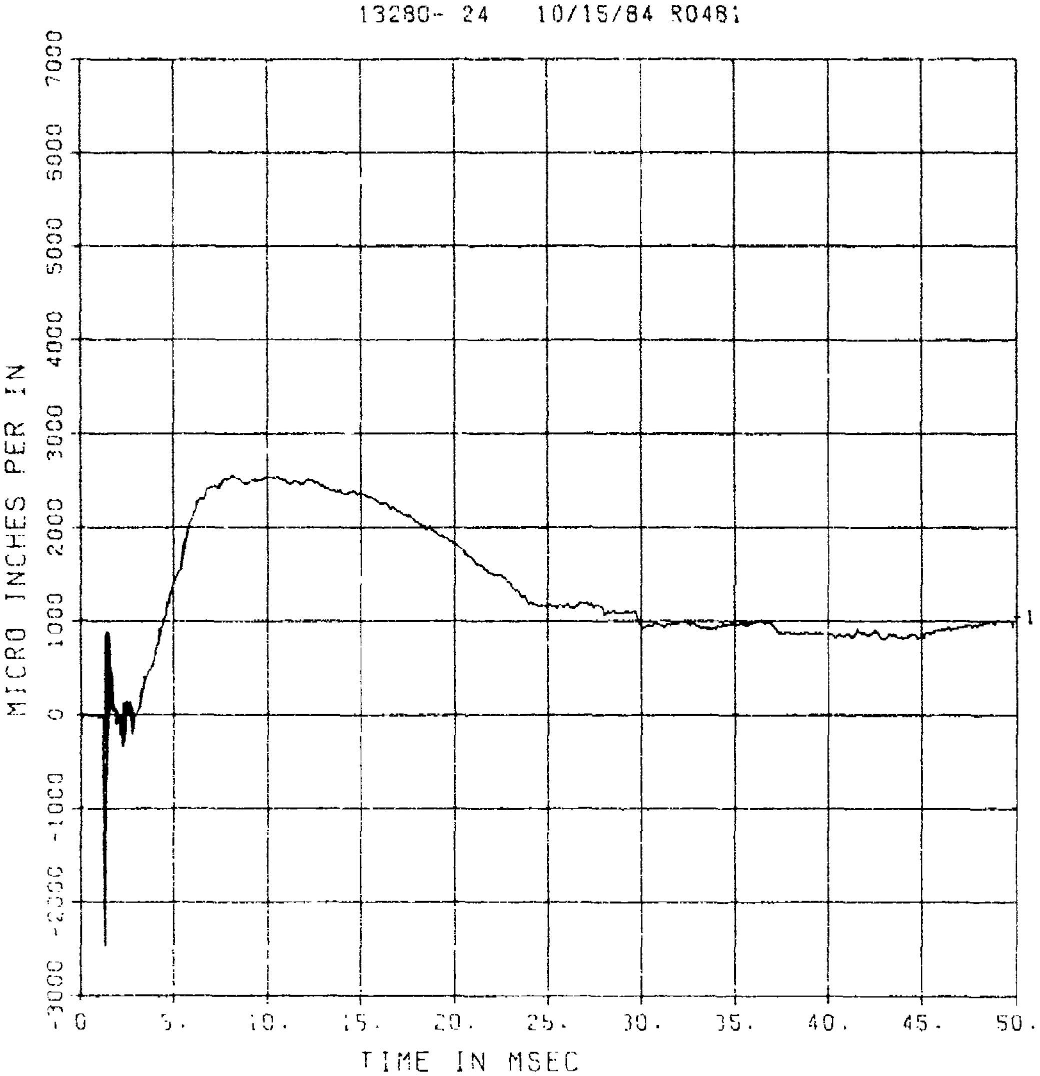
13280- 23 10/01/84 R0784



FEMA YIELD EFFECTS 3
EO-1
200000. HZ CAL= 6686.
LP2/0 70% CUTOFF= 18000. HZ

** **

13280- 24 10/15/84 R0481

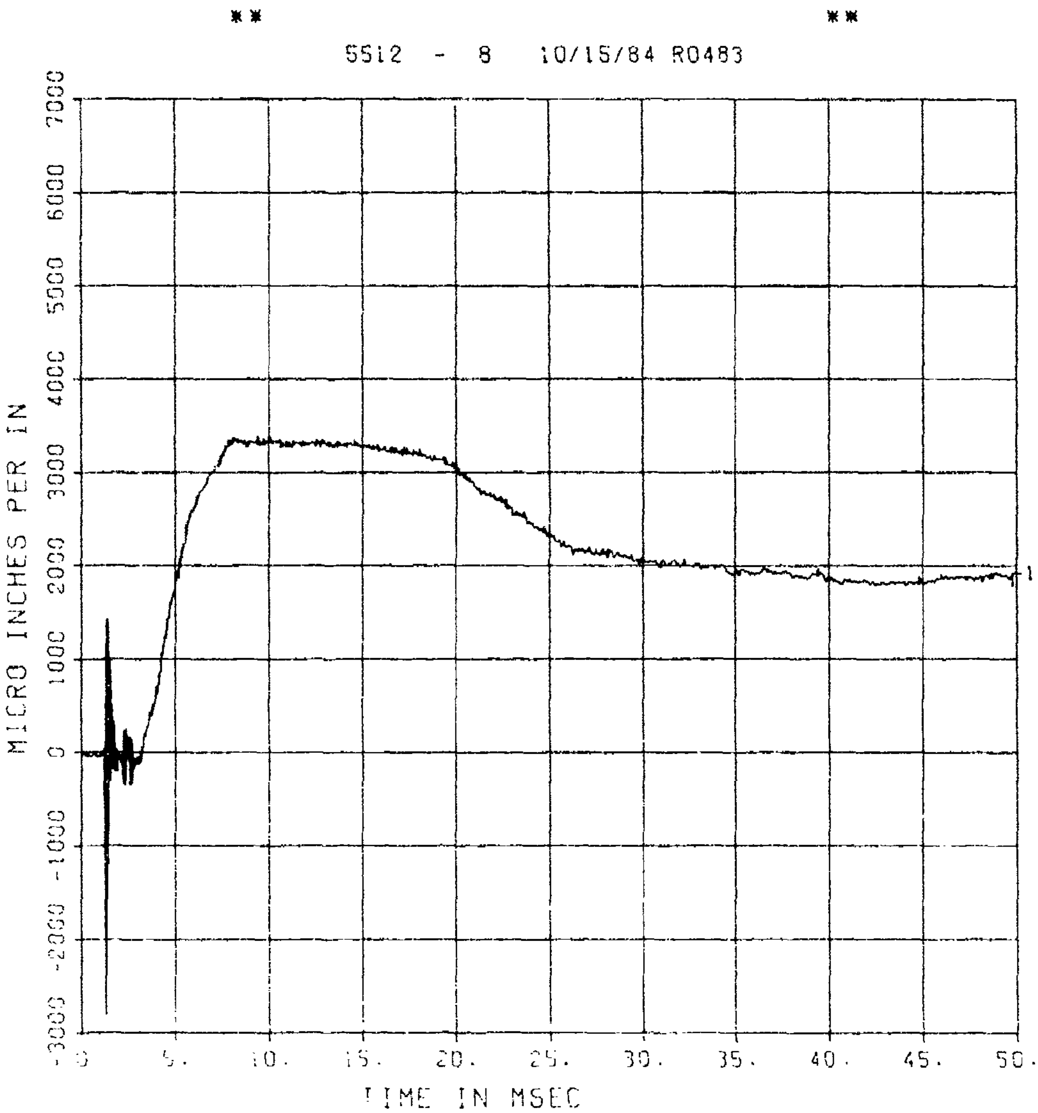


FEMA YIELD EFFECTS 3

EO-1A

200000. HZ CAL= 9975.

LP2/0 70% CUTOFF= 18000. HZ

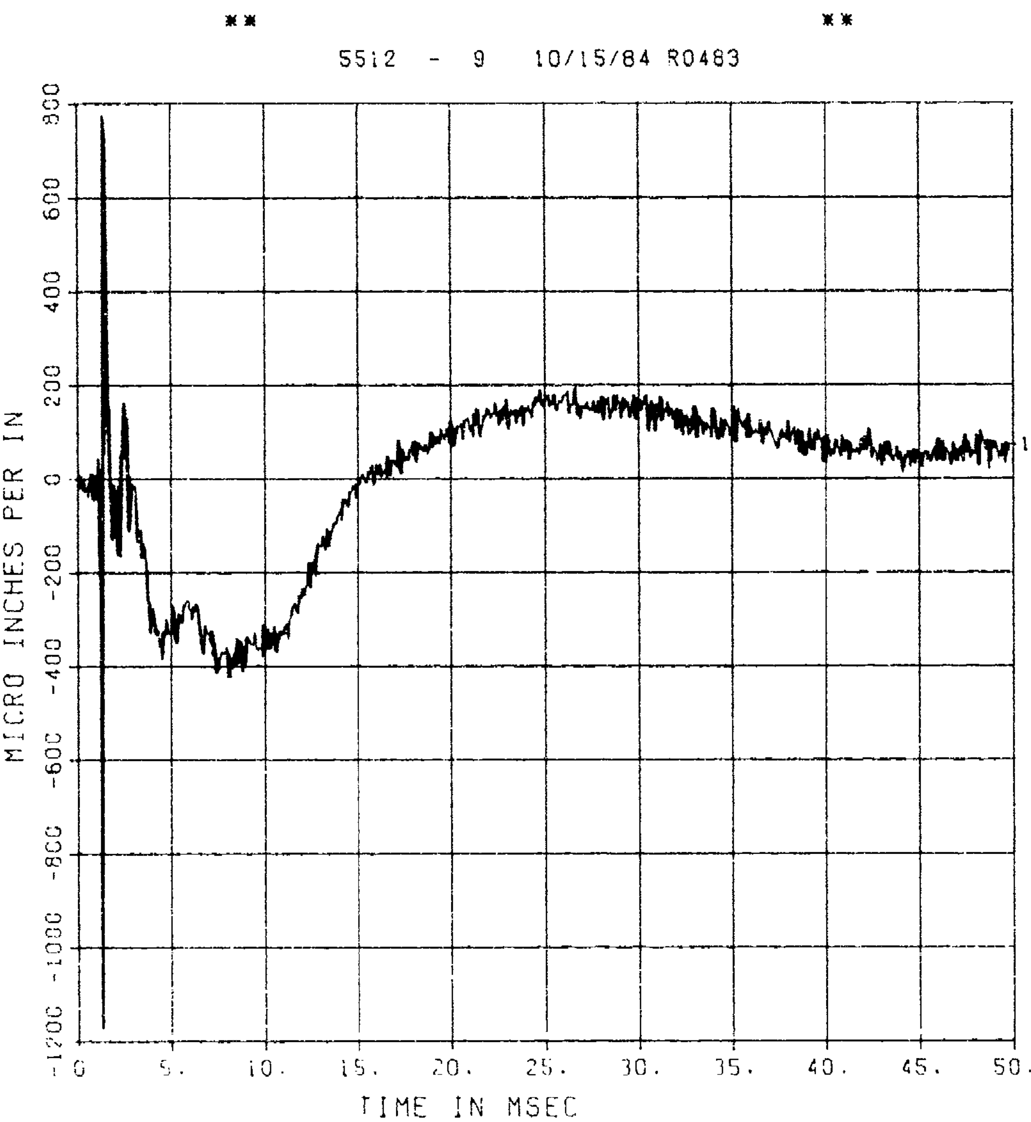


FEMA YIELD EFFECTS 3

EI-1A

200000. HZ CAL= 9975.

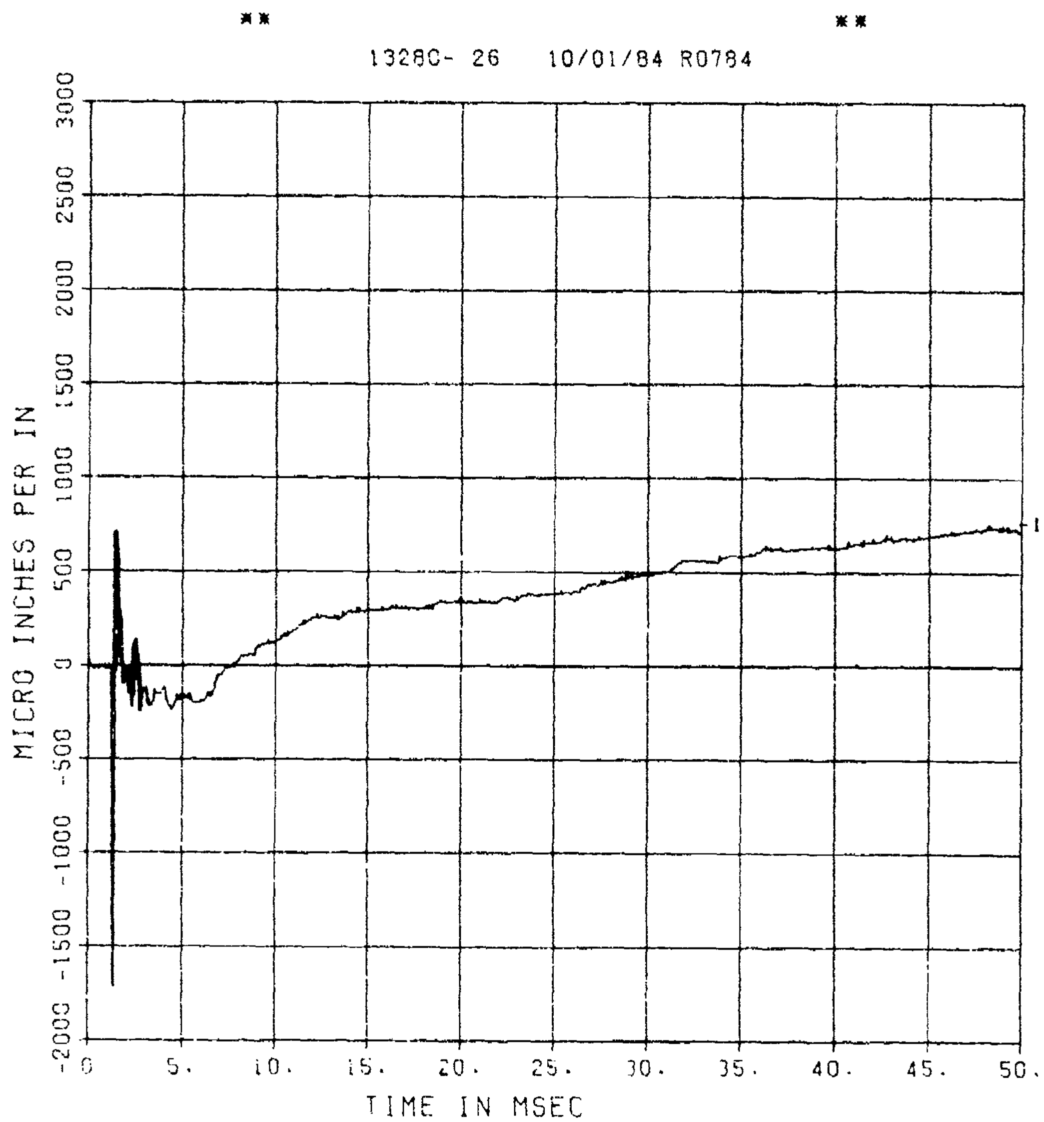
LP4/4 70% CUTOFF= 9000. HZ



FEMA YIELD EFFECTS 3

EO-2

200000. HZ CAL= 2023.

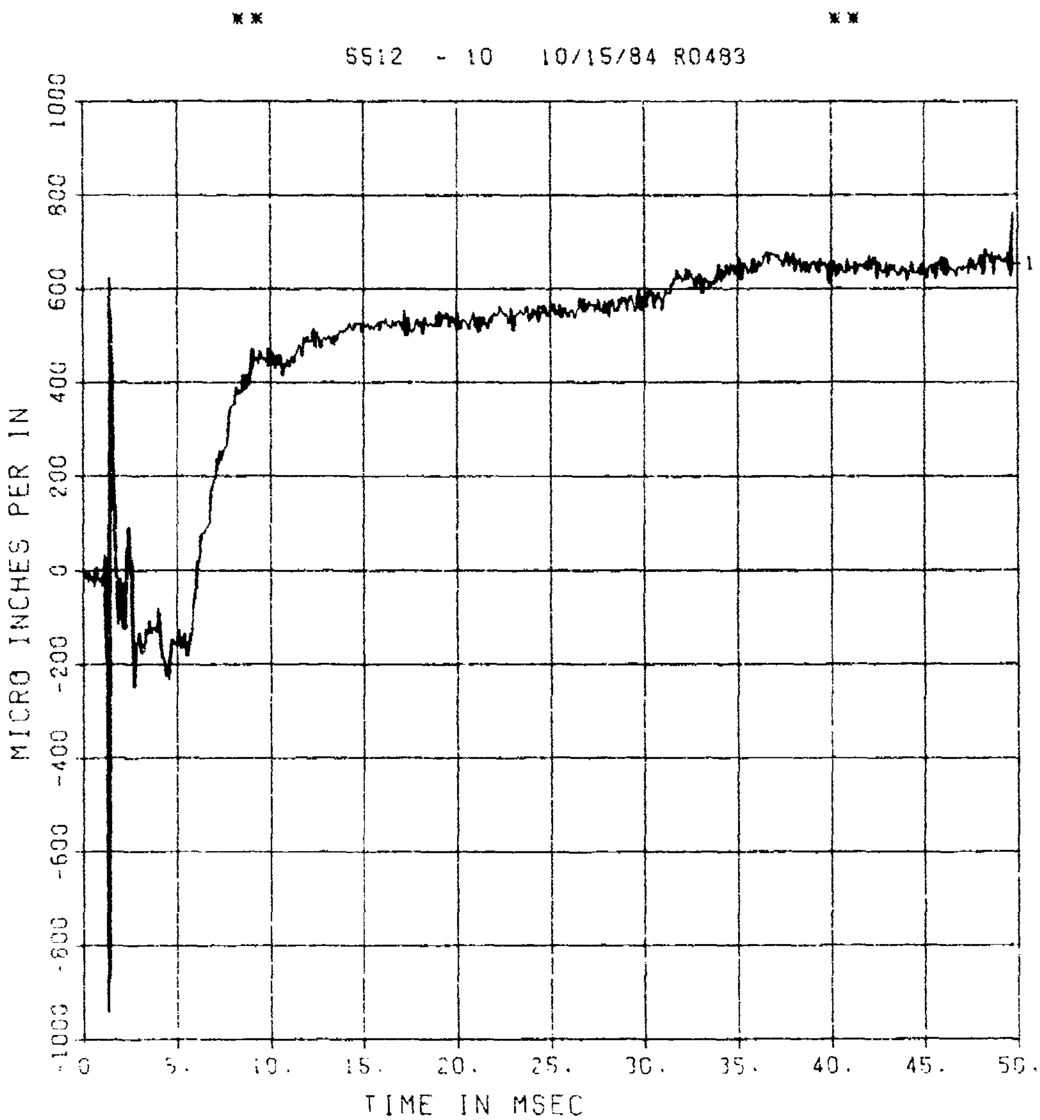


FEMA YIELD EFFECTS 3

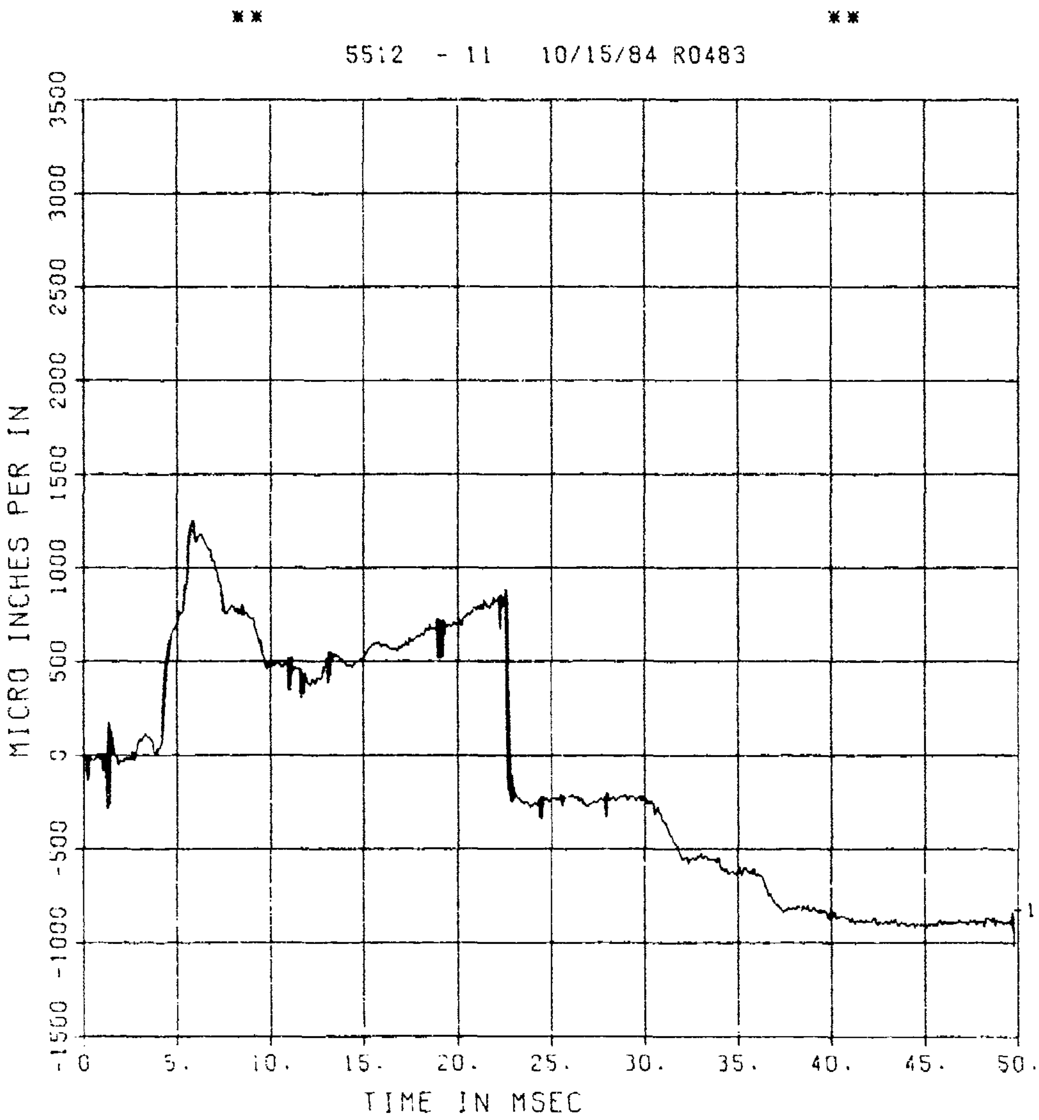
EO-2A

200000. HZ CAL= 6686.

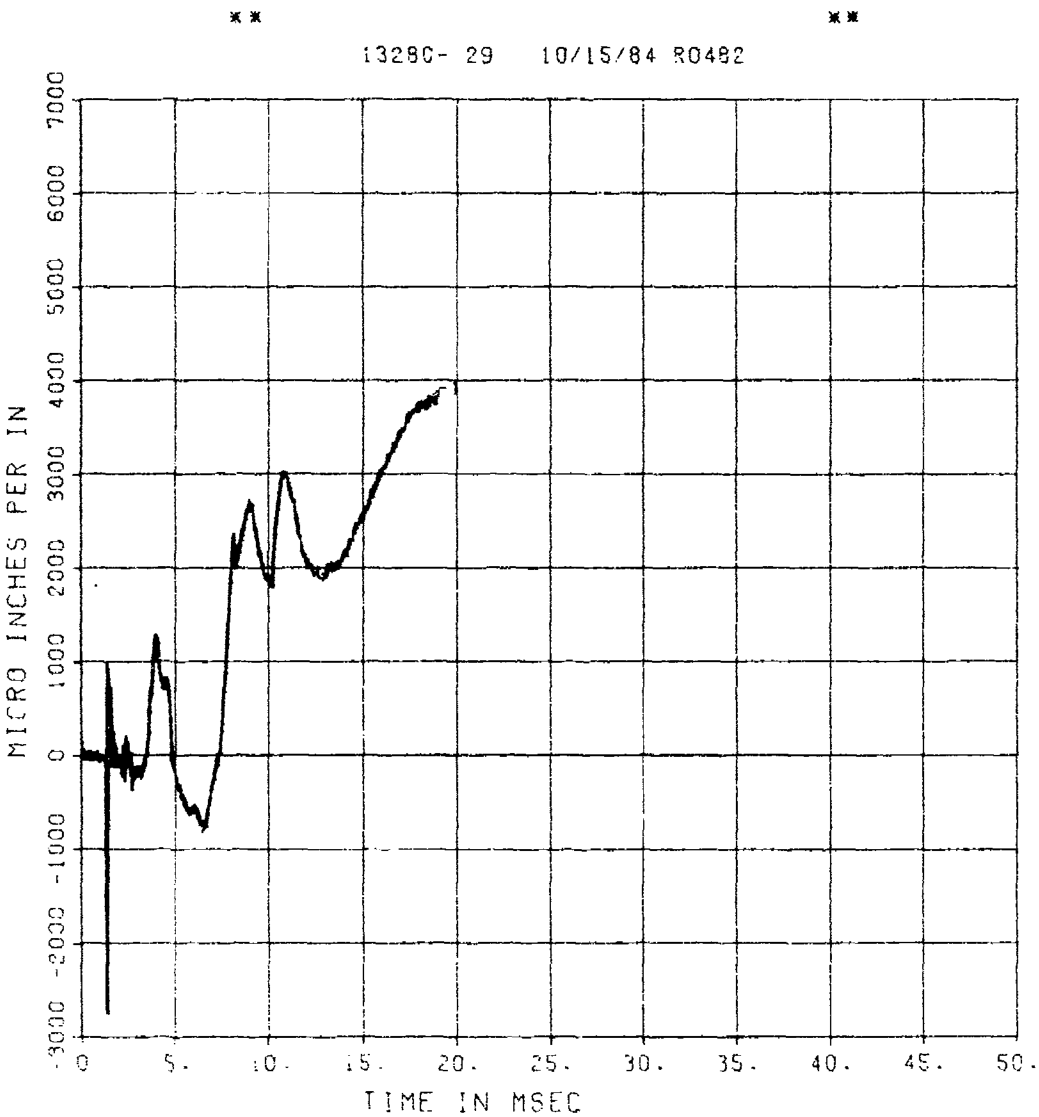
LP4/4 70% CUTOFF= 9000. HZ



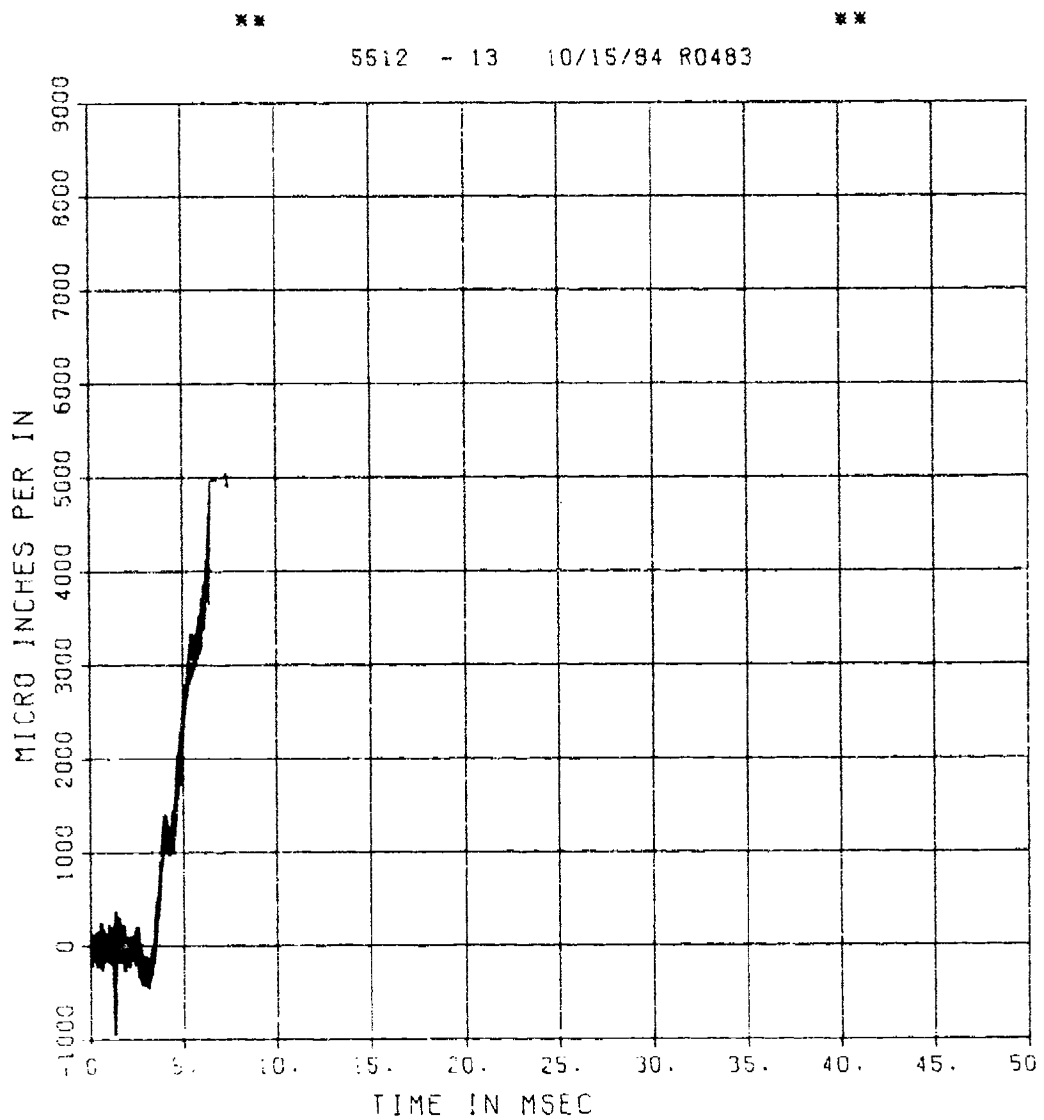
FEMA YIELD EFFECTS 3
EI-2A
200000. HZ CAL= 6686.
LP4/4 70% CUTOFF= 9000. HZ



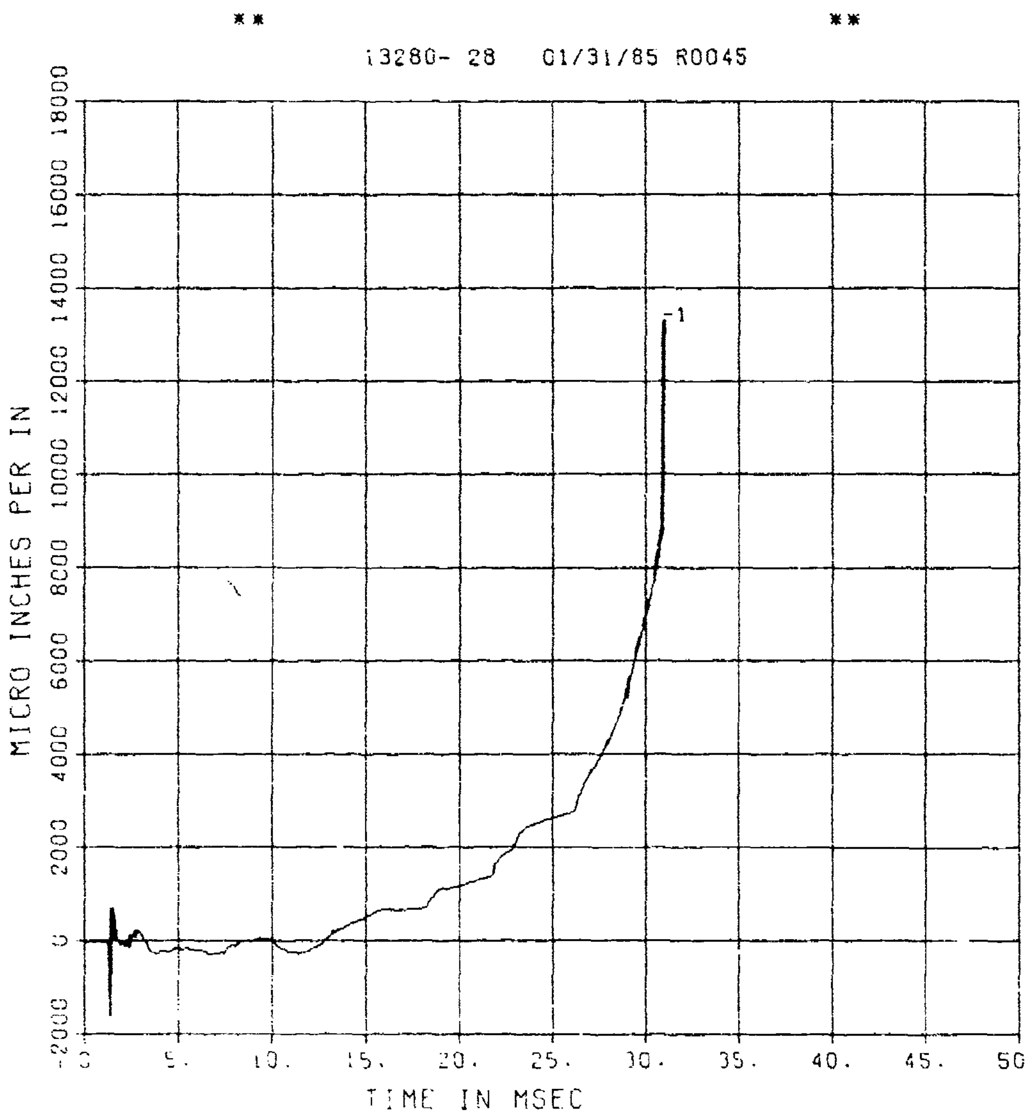
FEMA YIELD EFFECTS 3
EI-3
200000. HZ CAL= 9975.



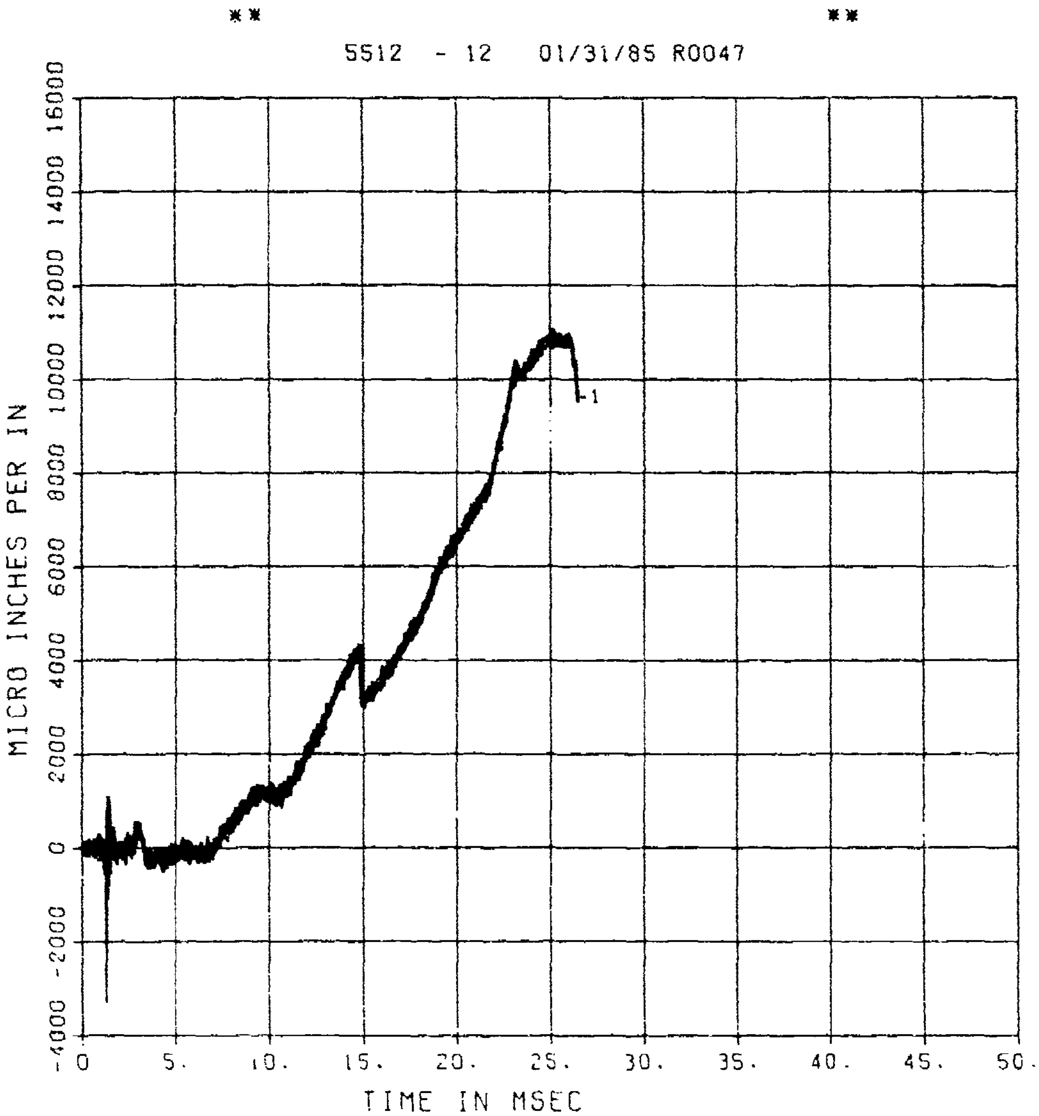
FEMA YIELD EFFECTS 3
EI-3A
200000. HZ CAL= 19614.



FEMA YIELD EFFECTS 3
EO-3
200000. HZ CAL= 6686.



FEMA YIELD EFFECTS 3
EO-3A
200000. HZ CAL= 19614.

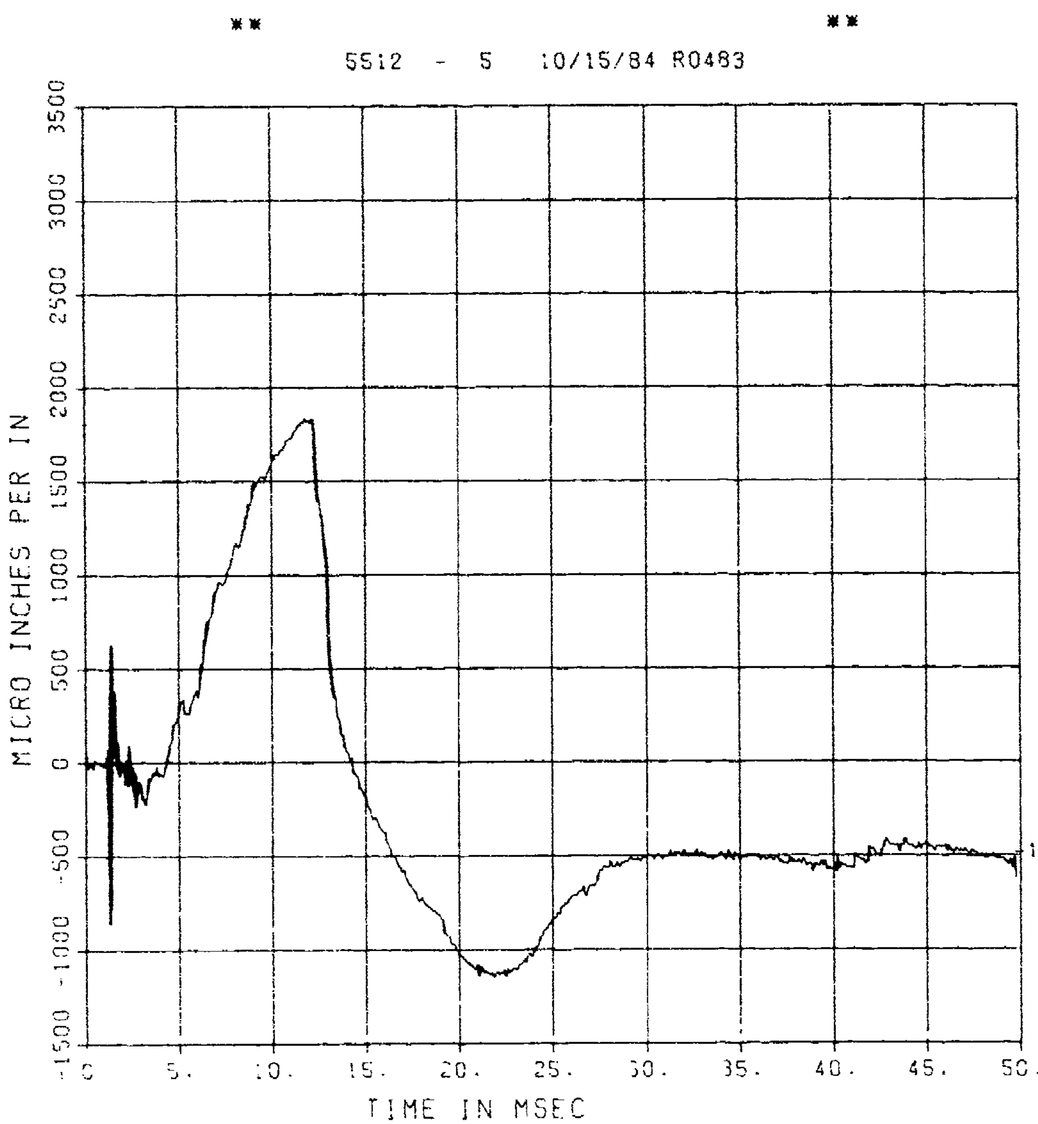


FEMA YIELD EFFECTS 3

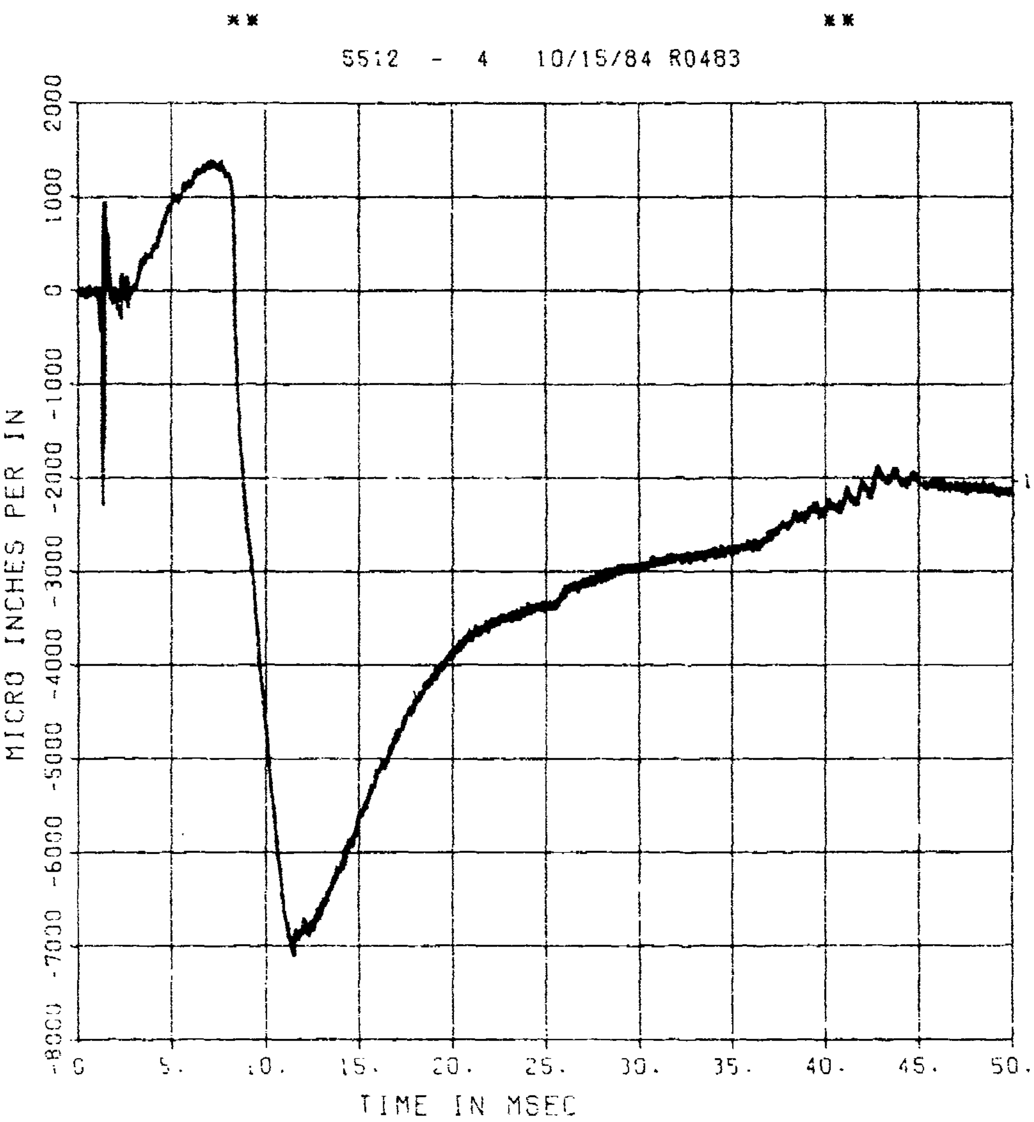
EI-4

200000. HZ CAL= 6686.

LP2/4 70% CUTOFF= 9000. HZ



FEMA YIELD EFFECTS 3
EO-4
200000. HZ CAL= 6686.

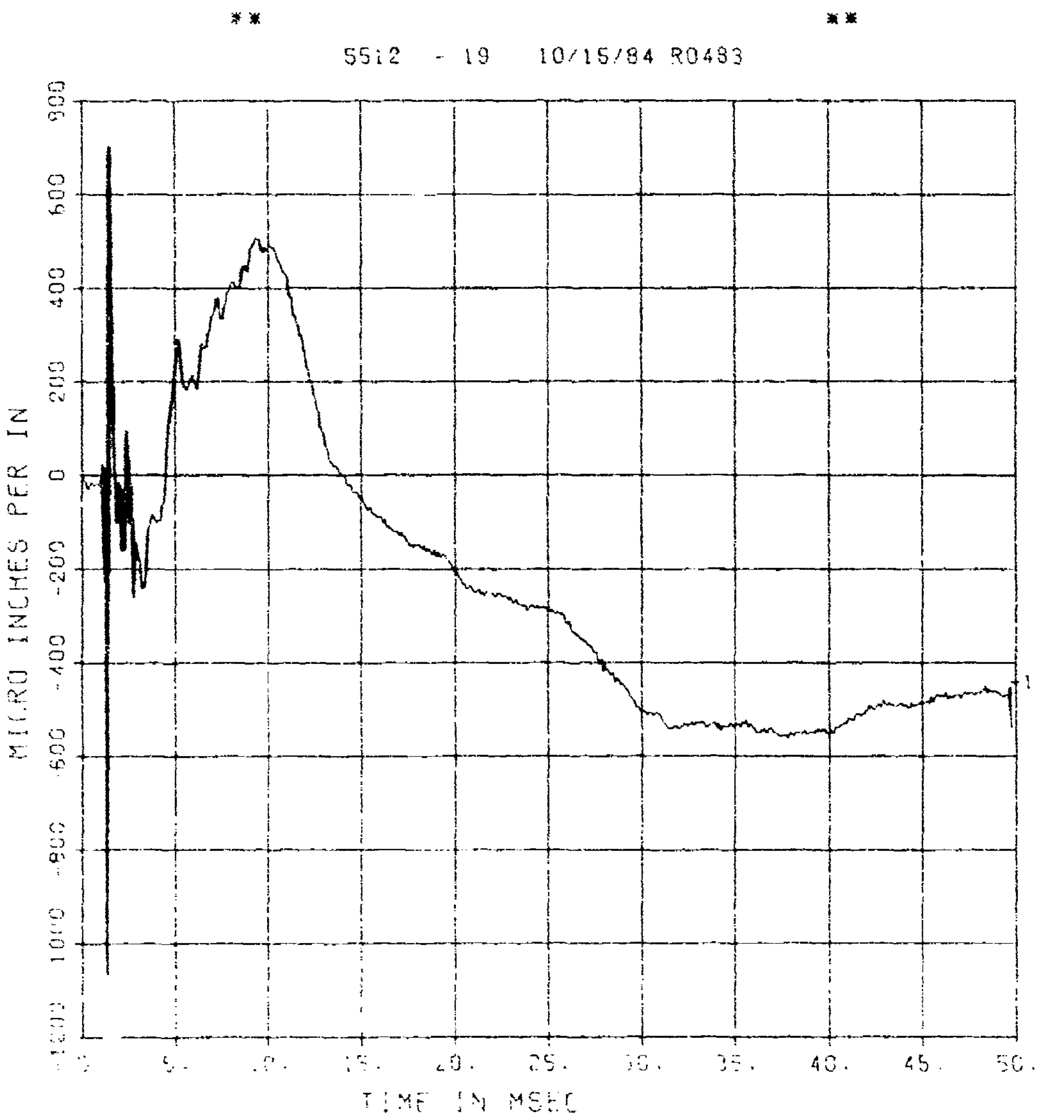


FEMA YIELD EFFECTS 3

EI-4A

200000. HZ CAL= 2023.

LP4/4 70% CUTOFF= 9000. HZ

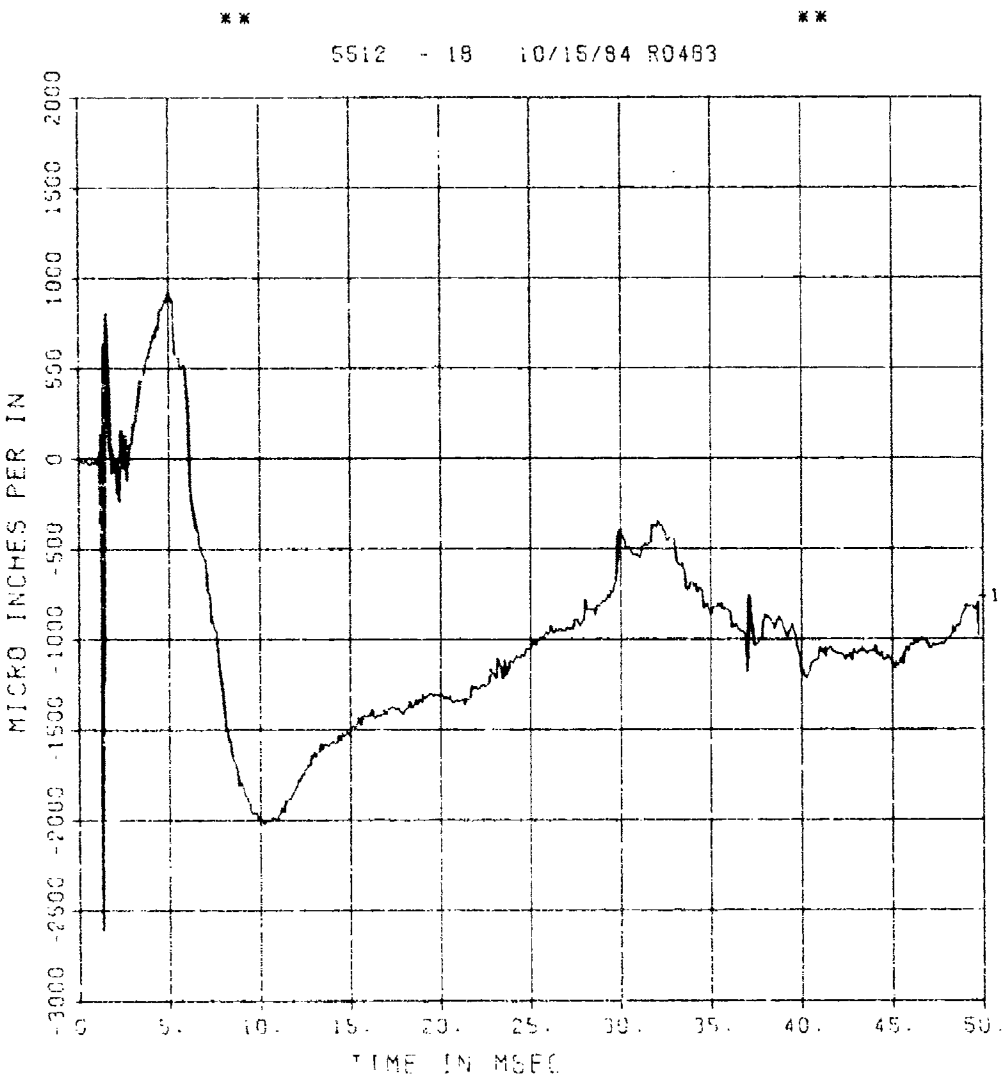


FEMA YIELD EFFECTS 3

E0-4A

200000. HZ CAL= 6686.

LP2/4 70% CUTOFF= 9000. HZ

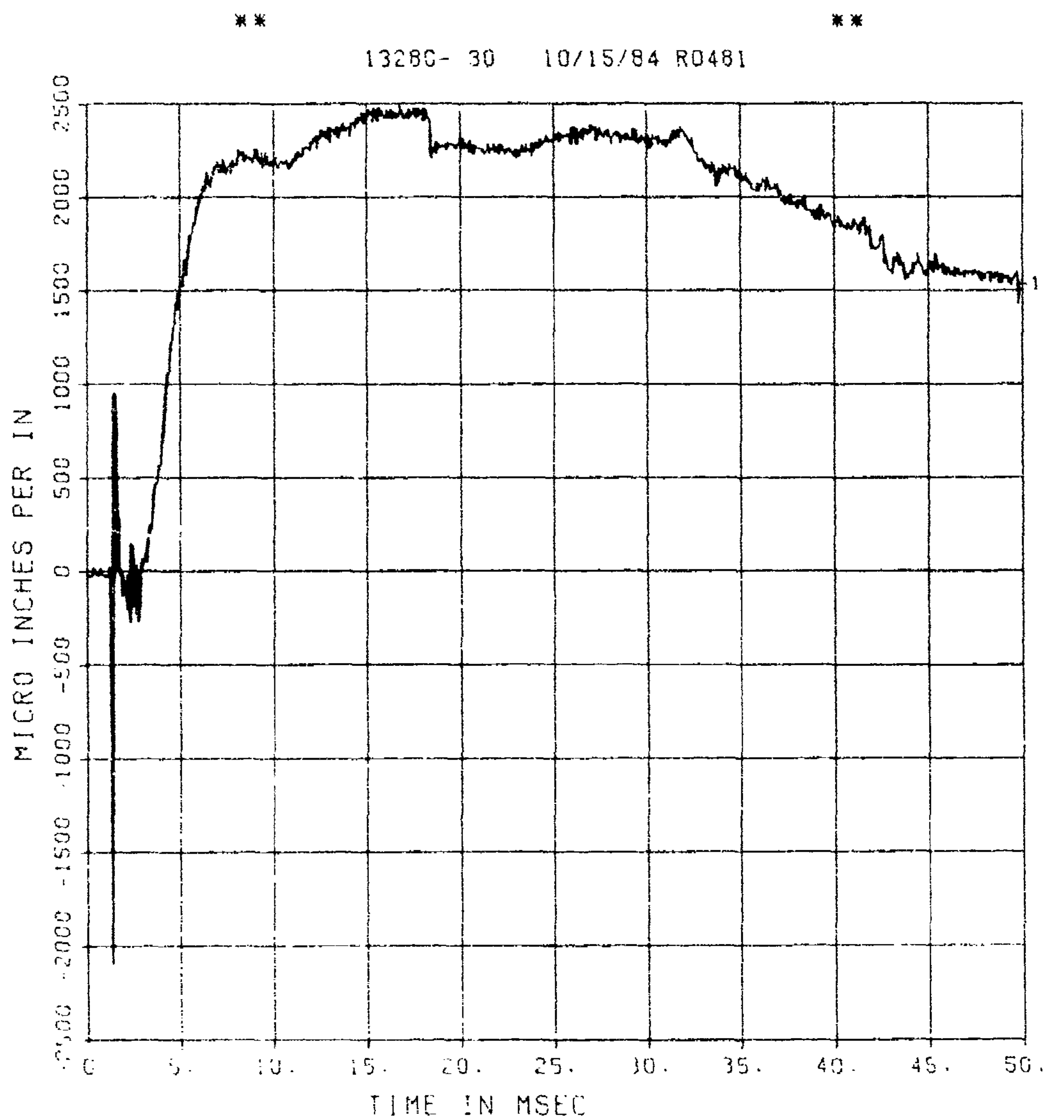


FEMA YIELD EFFECTS 3

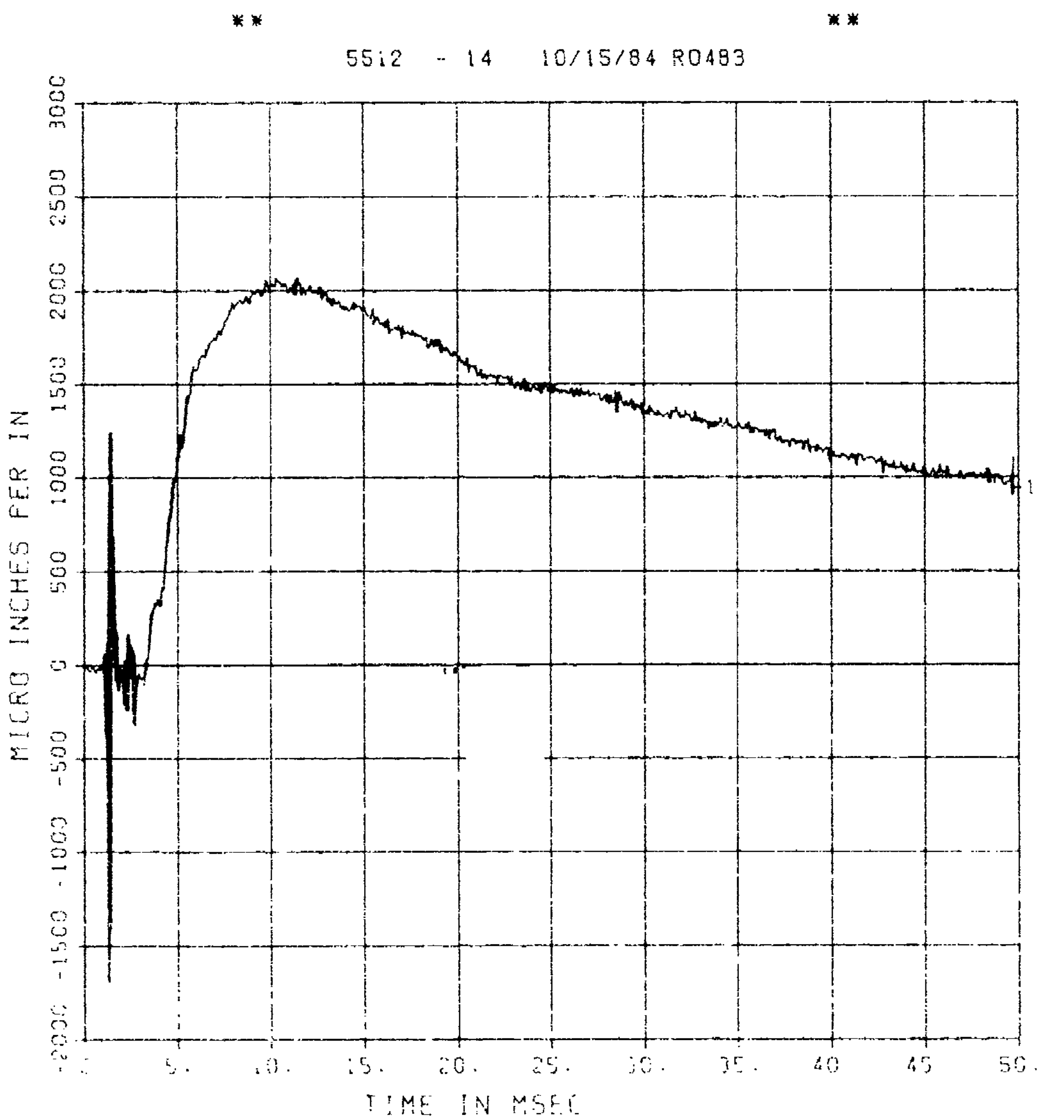
E-5

200000. HZ CAL= 9975.

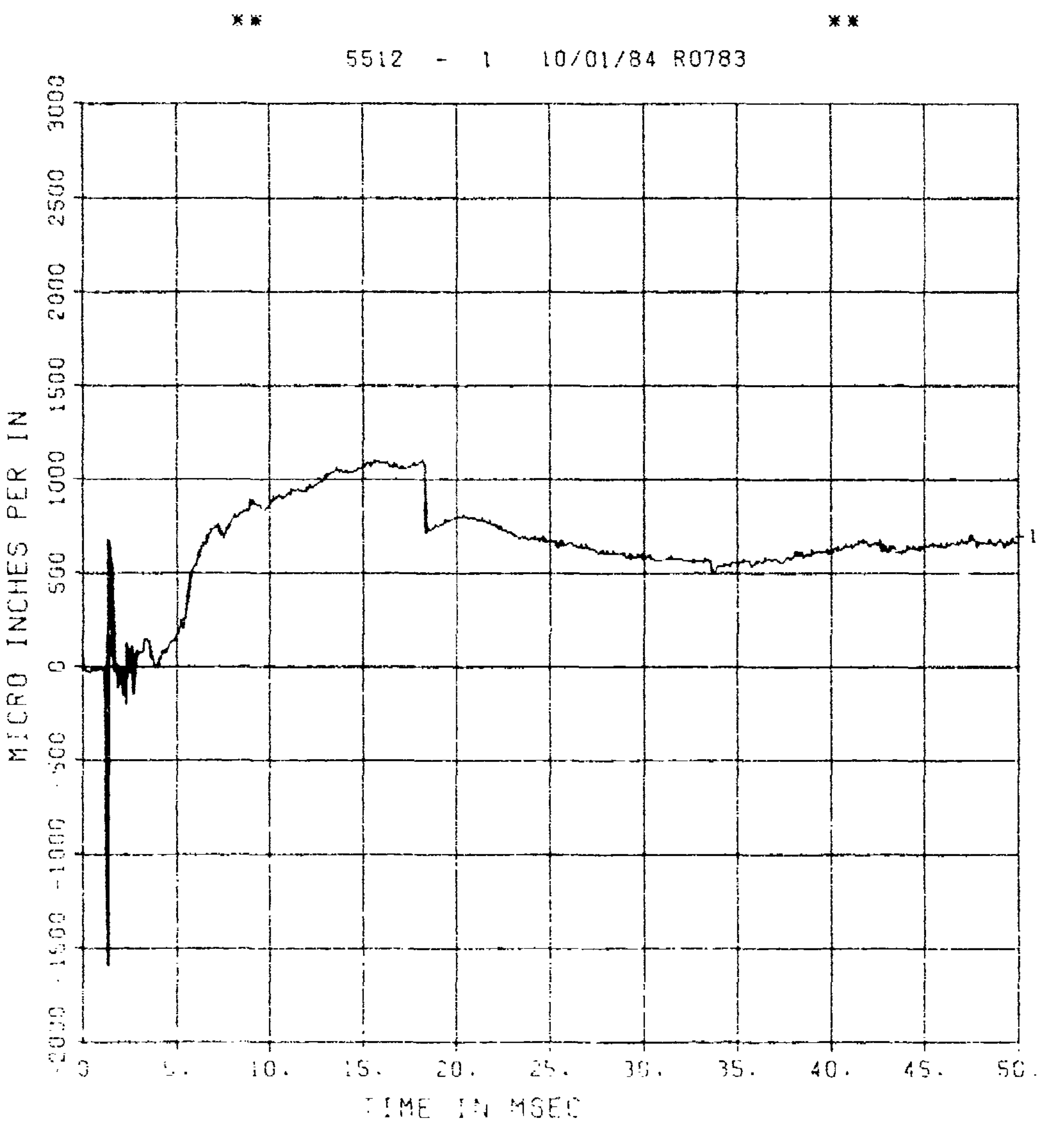
LP2/0 70% CUTOFF= 18000. HZ



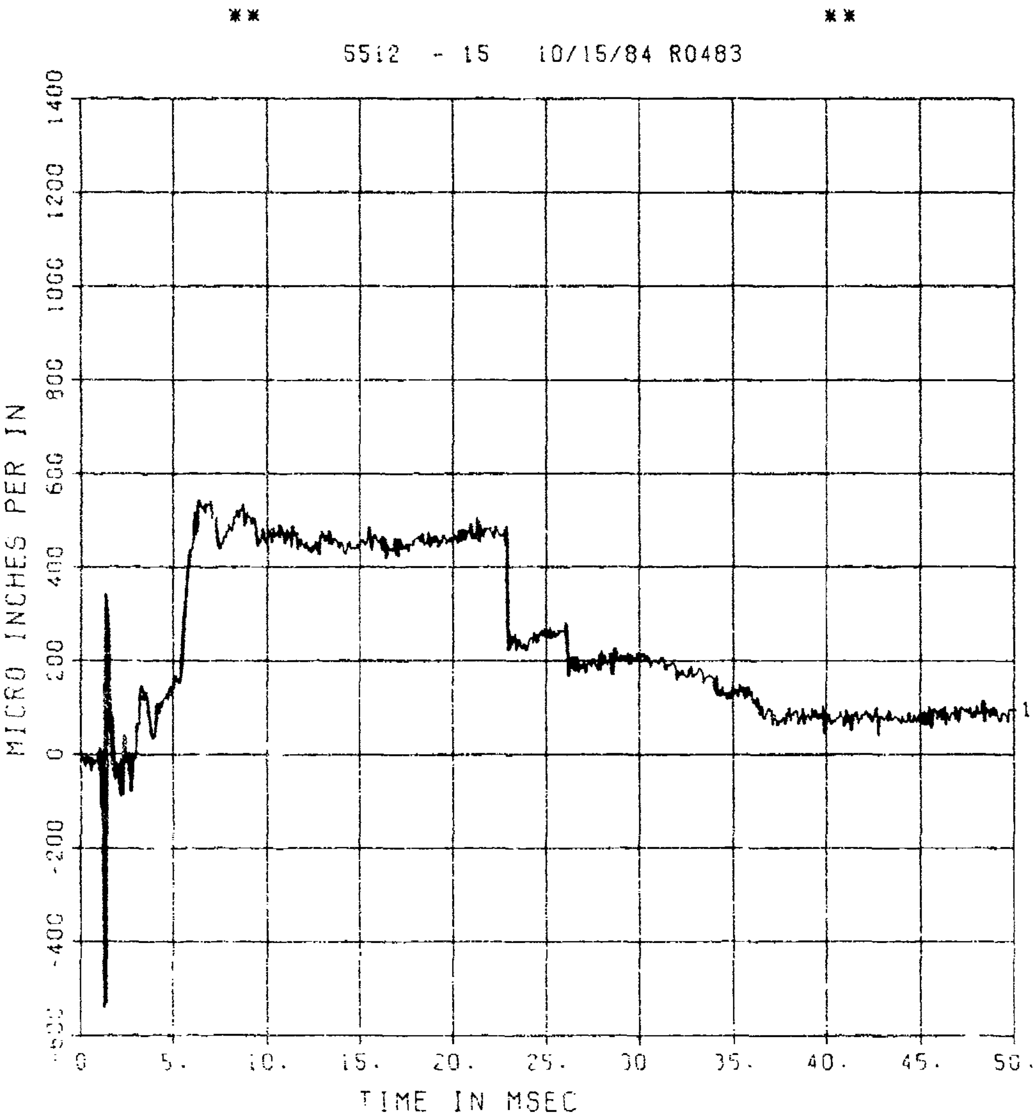
FEMA YIELD EFFECTS 3
E5-A
200000. HZ CAL= 9975.
LP2/4 70% CUTOFF= 9000. HZ



FEMA YIELD EFFECTS 3
E-6
200000. HZ CAL= 2023.



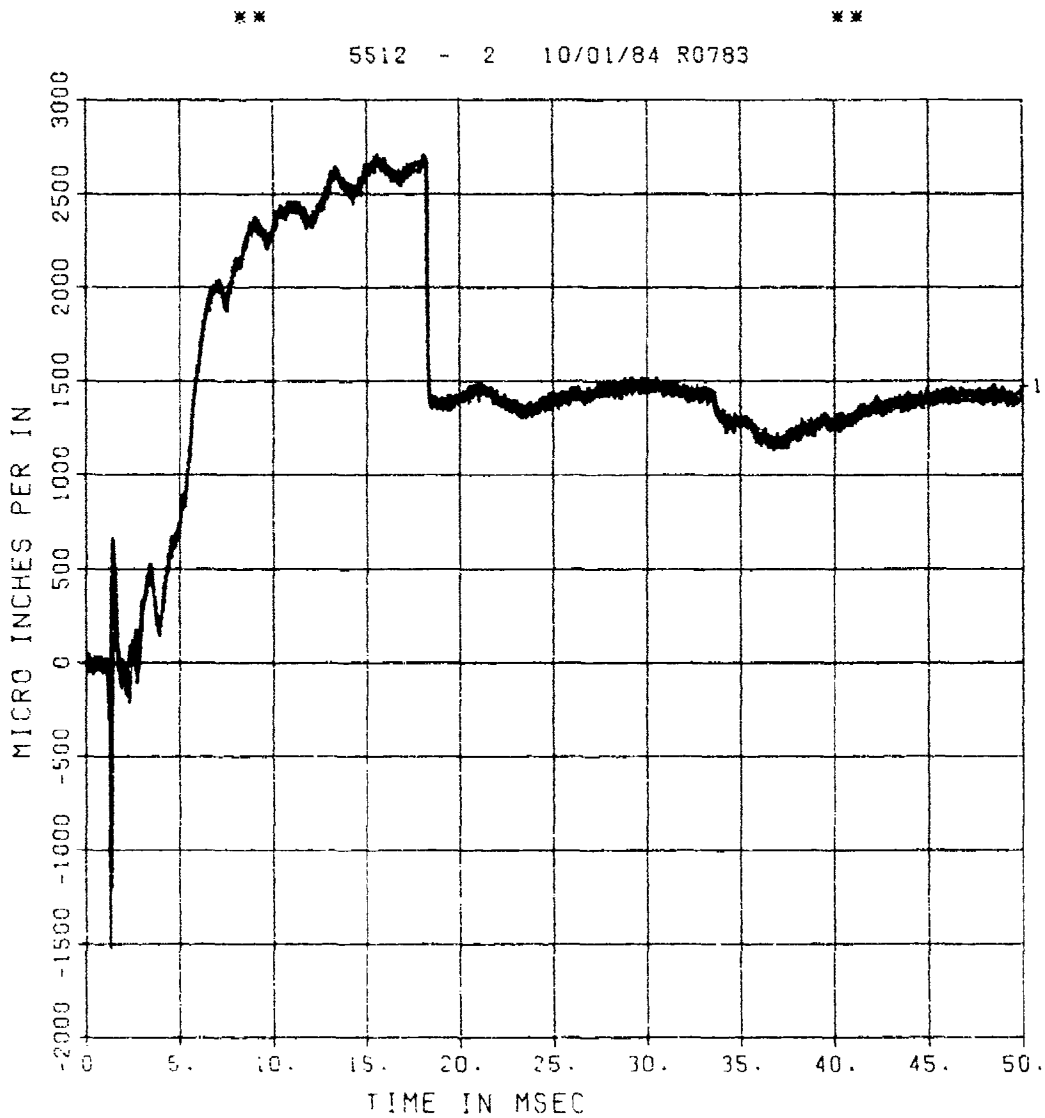
FEMA YIELD EFFECTS 3
E6-A
200000. HZ CAL= 6686.
LP4/4 70% CUTOFF= 9000. HZ



FEMA YIELD EFFECTS 3

E-7

200000. HZ CAL= 6686.

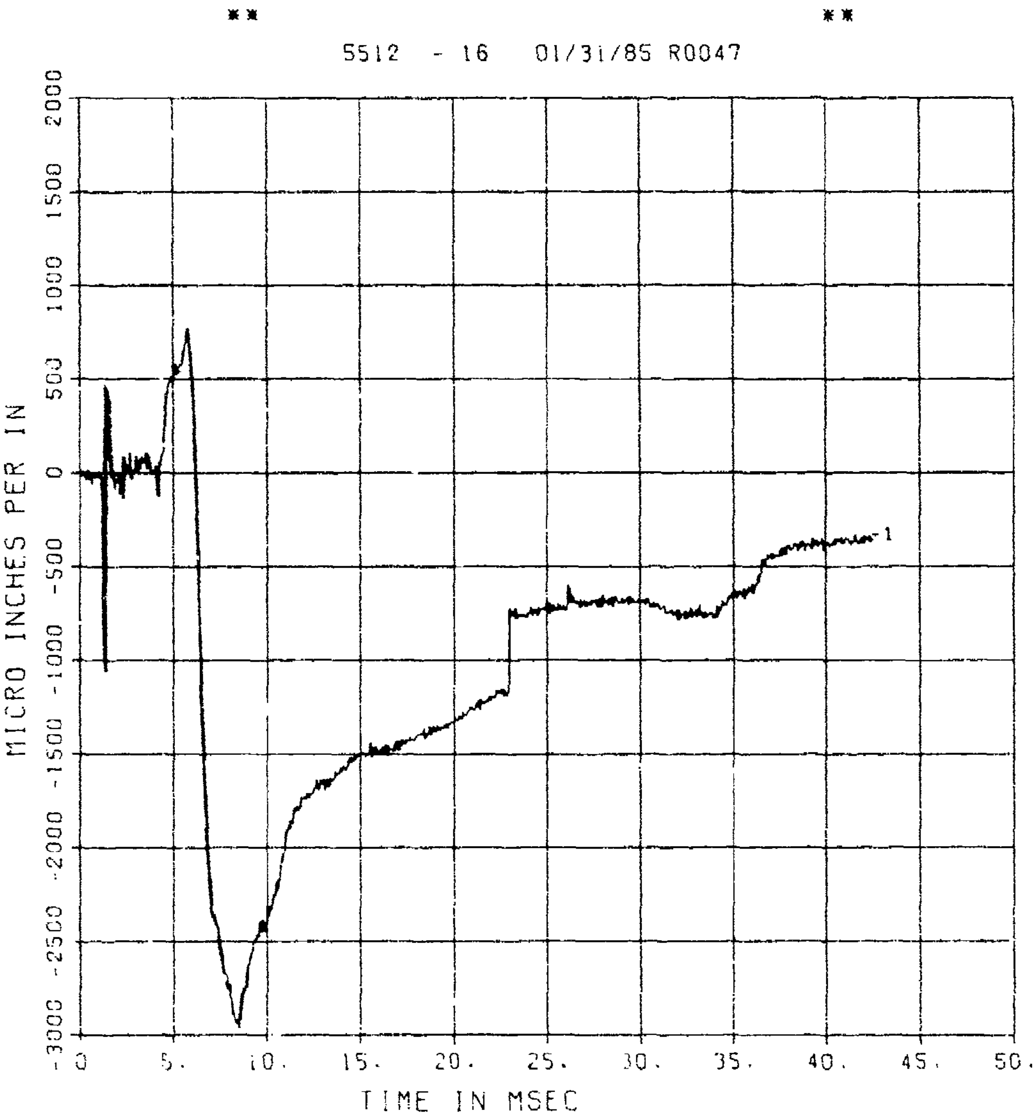


FEMA YIELD EFFECTS 3

E7-A

200000. HZ CAL= 6686.

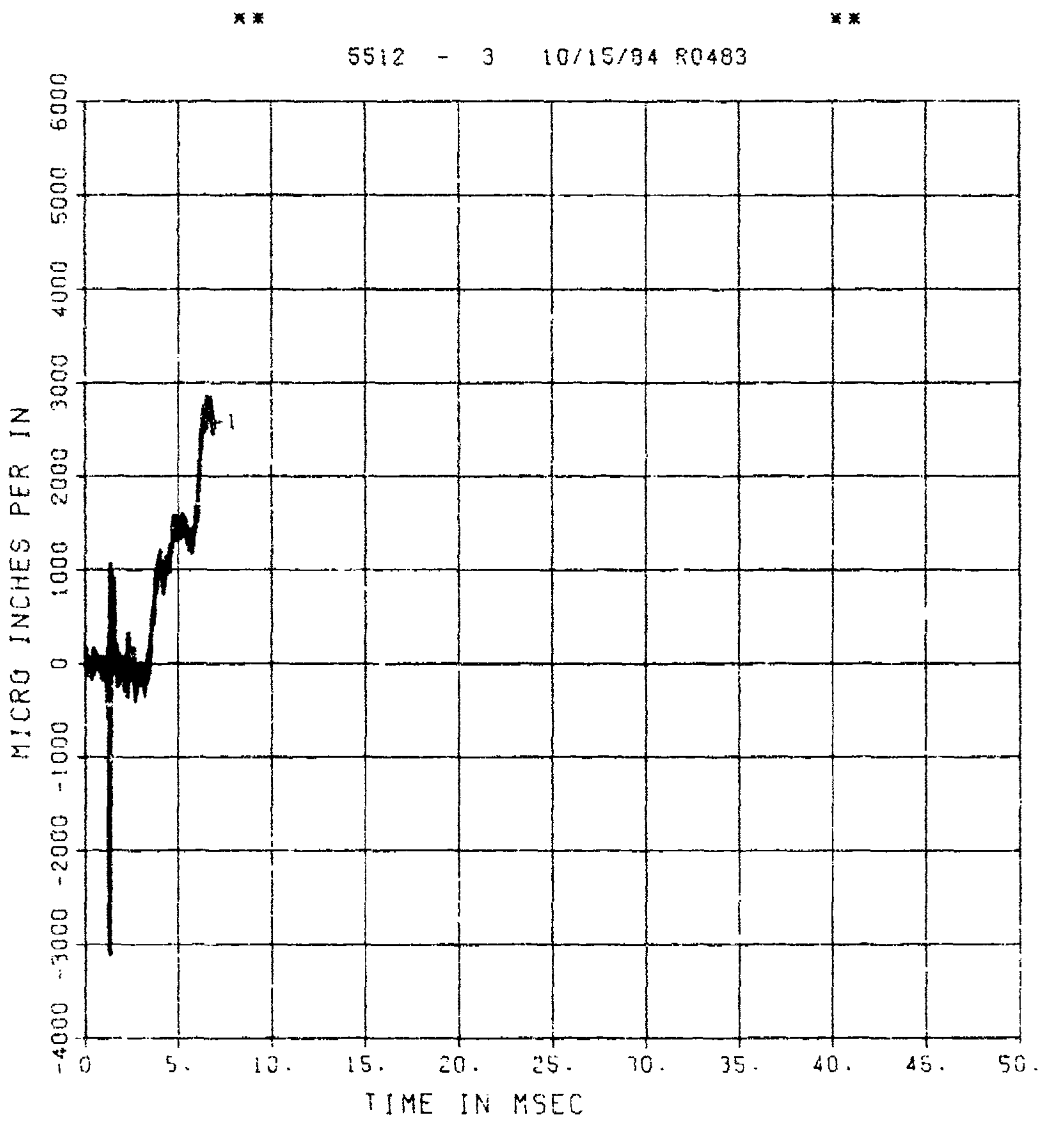
LP2/0 70% CUTOFF= 18000. HZ



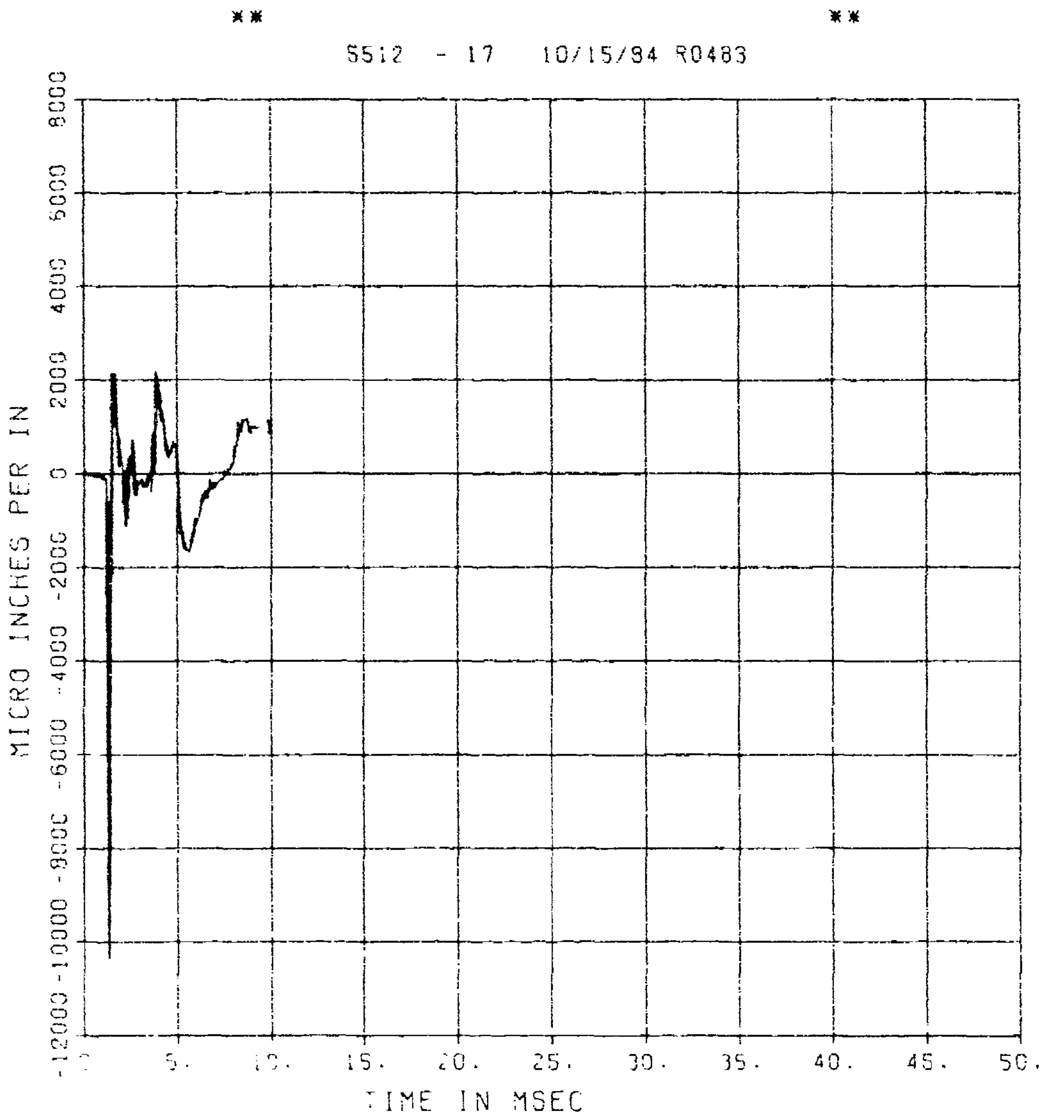
FEMA YIELD EFFECTS 3

E-8

200000. HZ CAL= 27067.



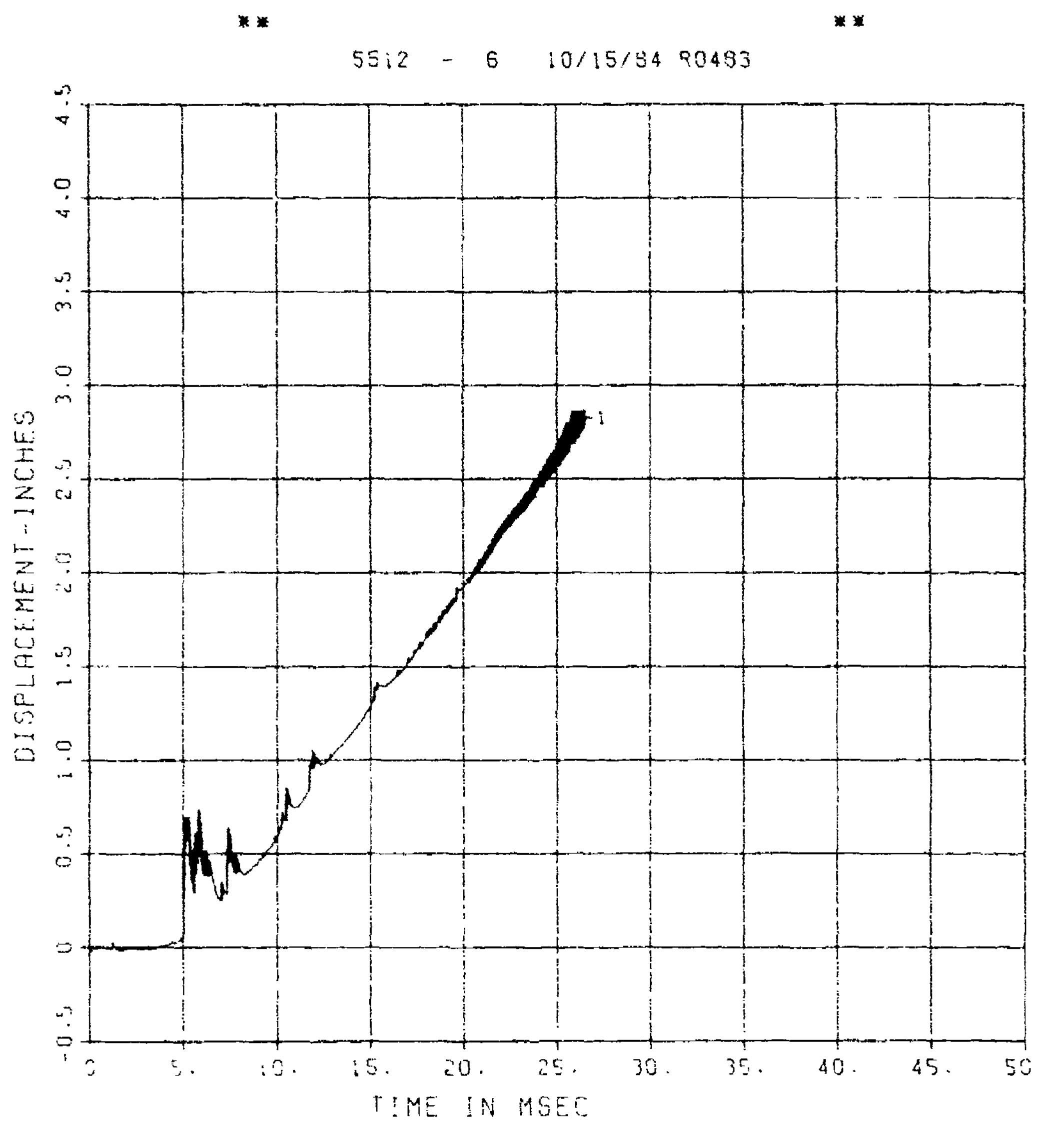
FEMA YIELD EFFECTS 3
E8-A
200000. HZ CAL= 9985.



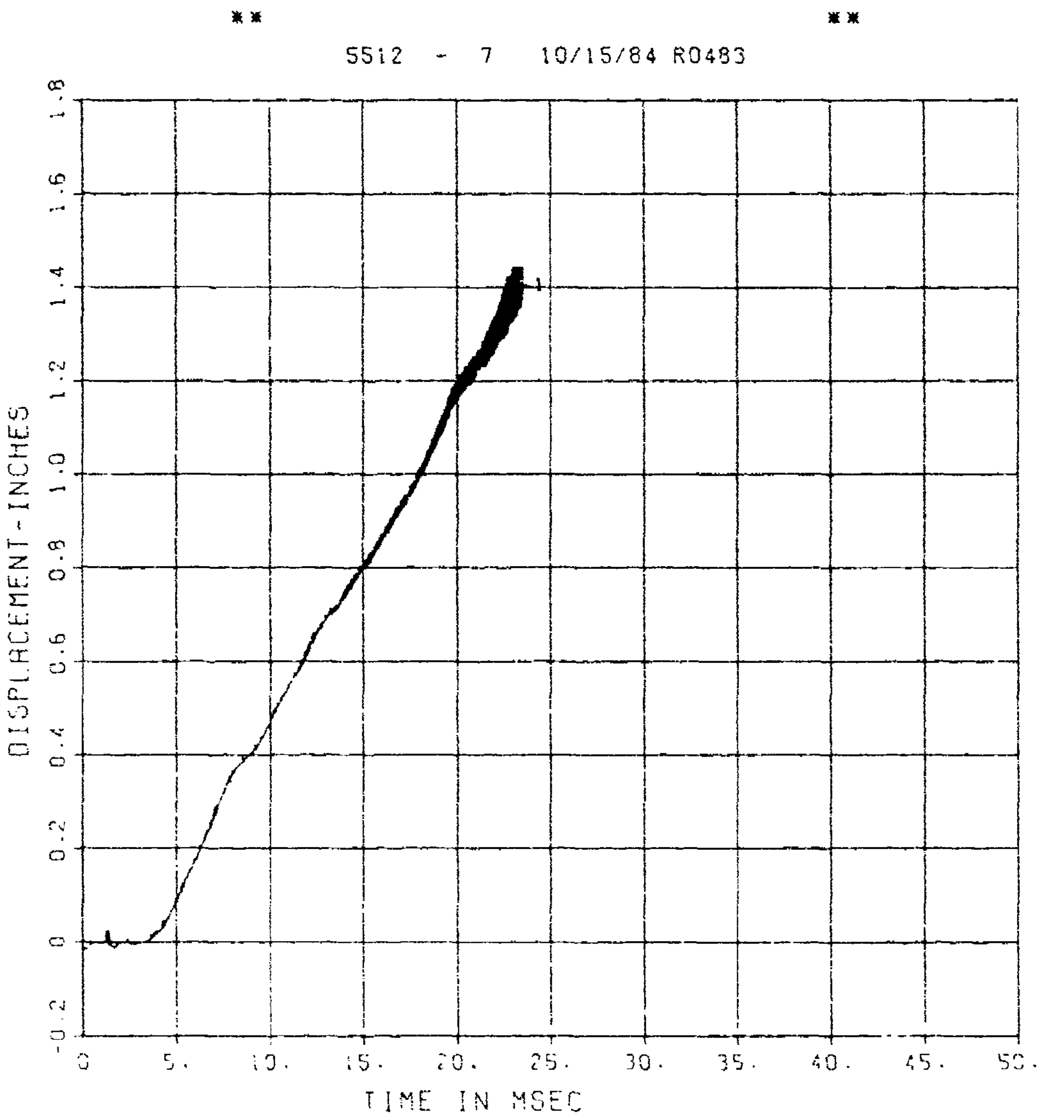
FEMA YIELD EFFECTS 3

D-1

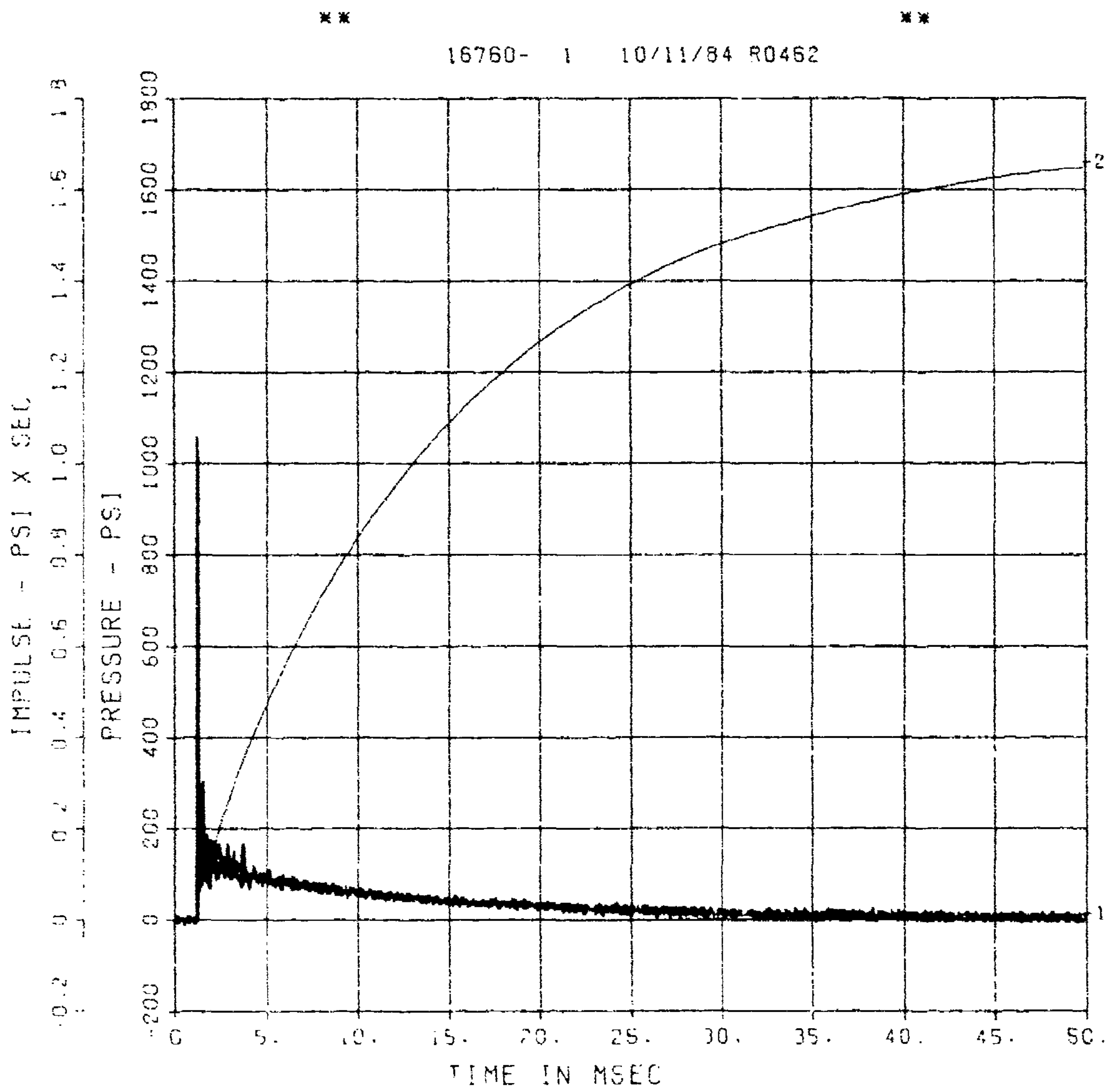
200000. HZ CAL= 1.435



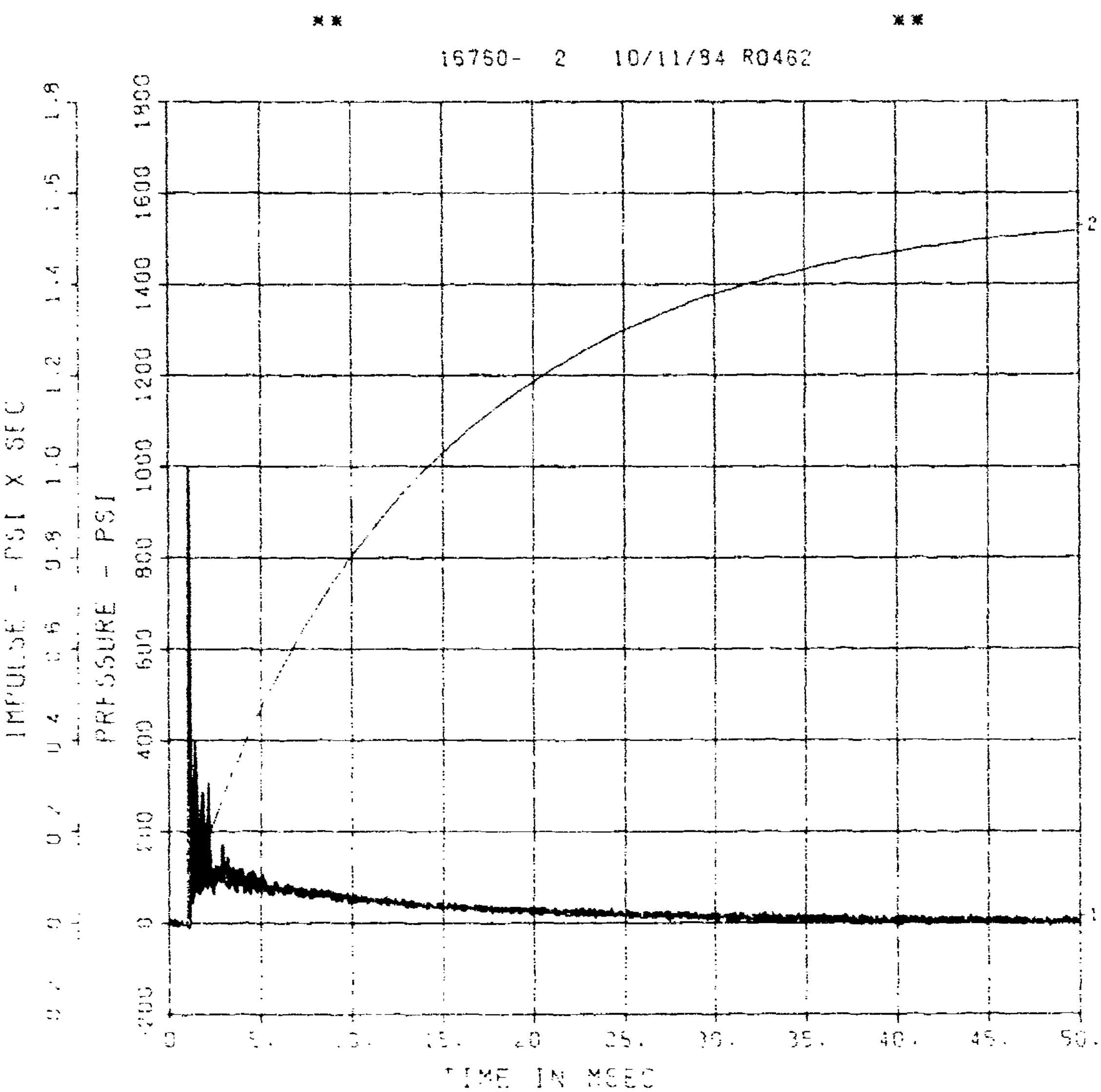
FEMA YIELD EFFECTS 3
D-2
200000. HZ CAL= 0.719



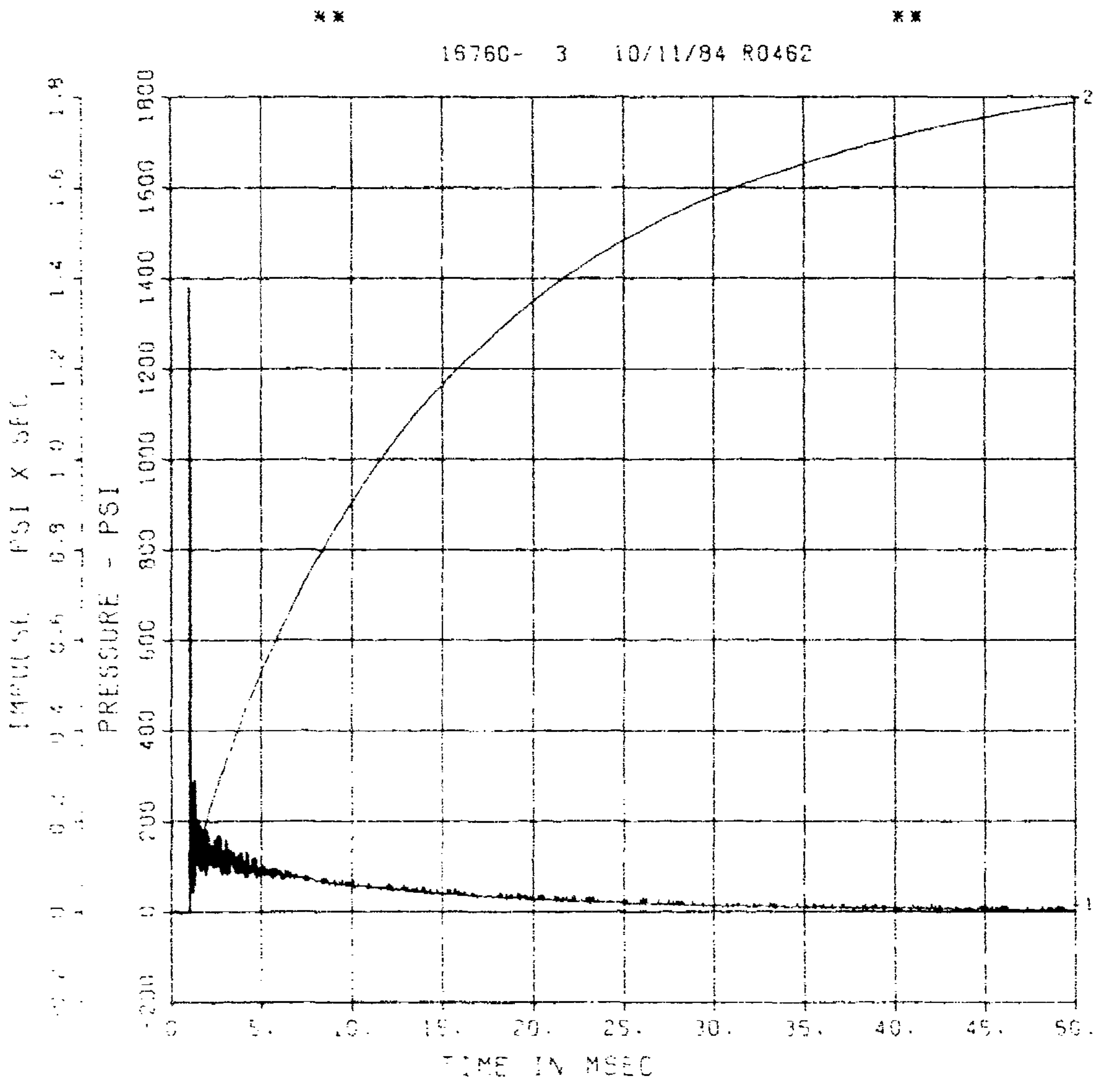
FEMA YIELD EFFECTS 4
BP-1
200000. HZ CAL= 1518.



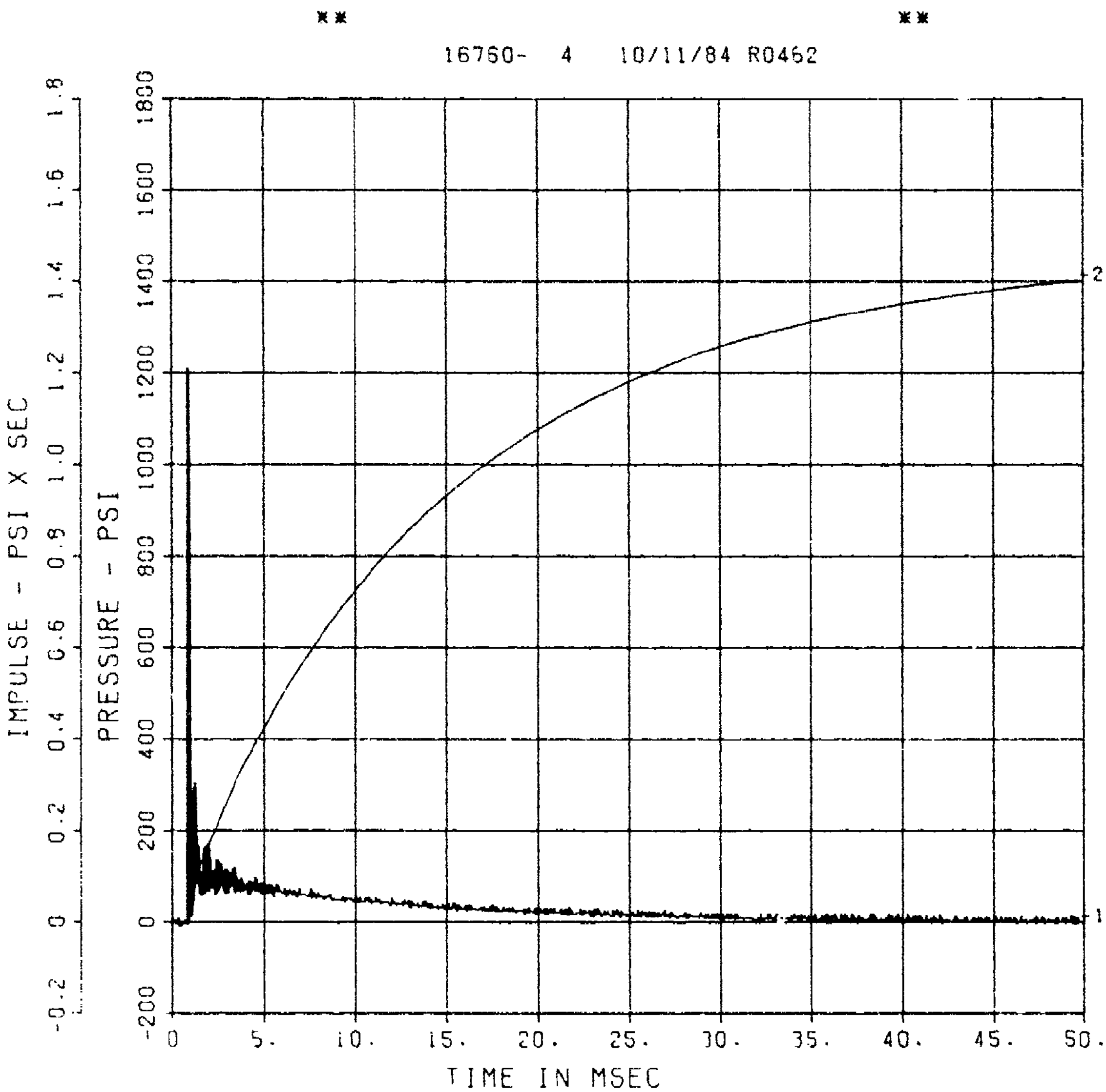
FEMA YIELD EFFECTS 4
BP-2
200000. HZ CAL= 1406.



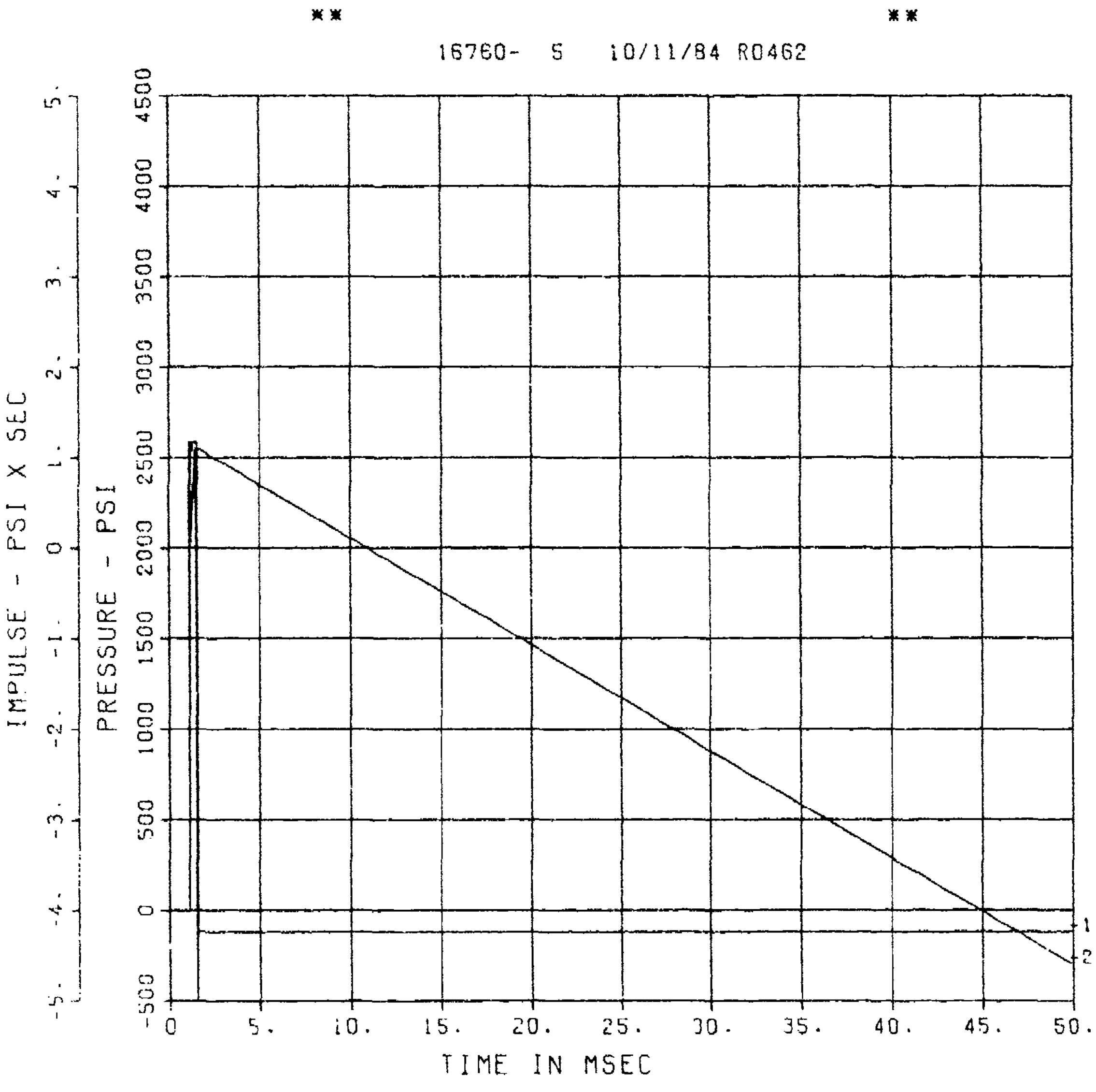
FEMA YIELD EFFECTS 4
BP-3
200000. HZ CAL= 1120.



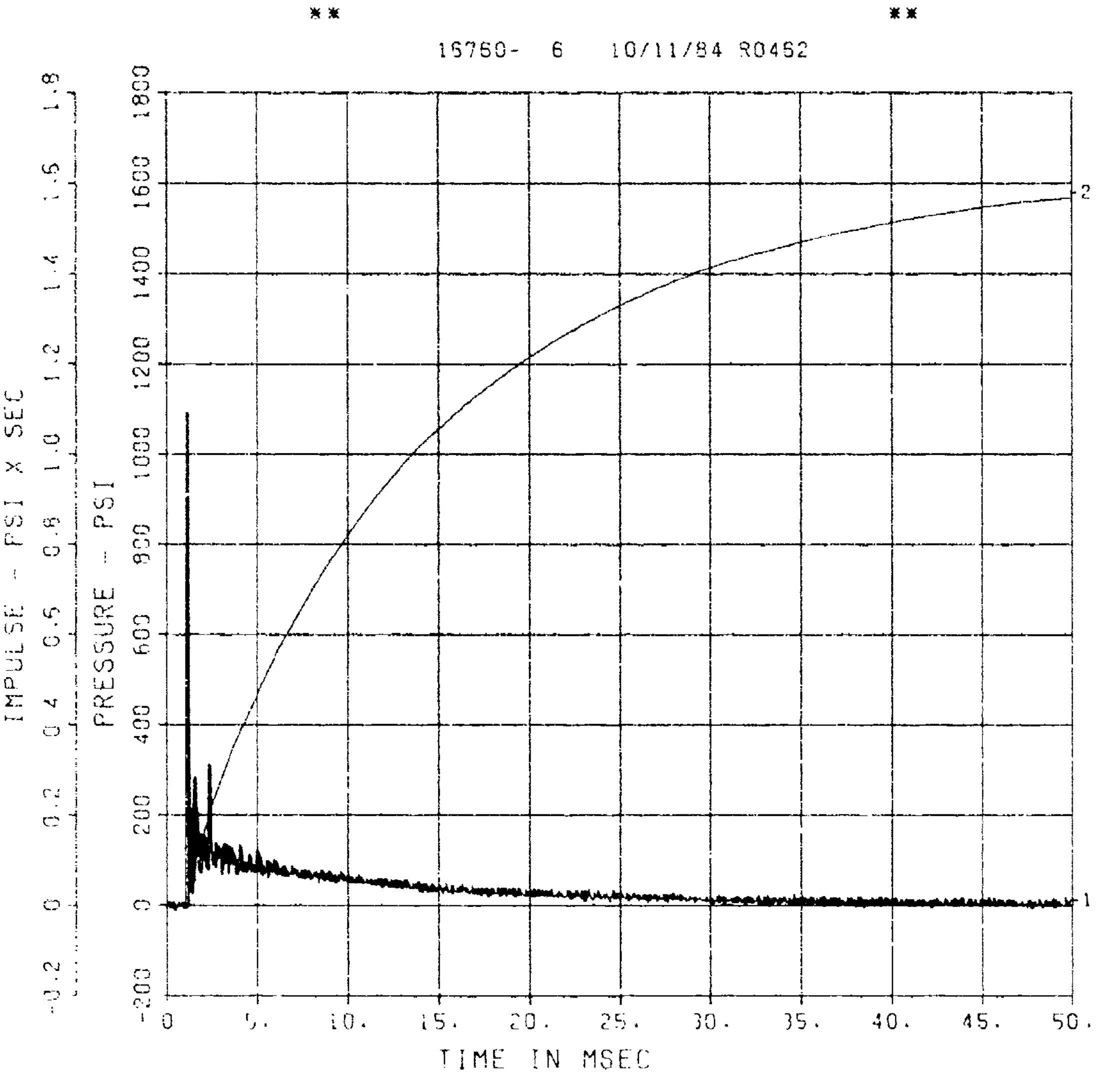
FEMA YIELD EFFECTS 4
BP-4
200000. HZ CAL= 1155.



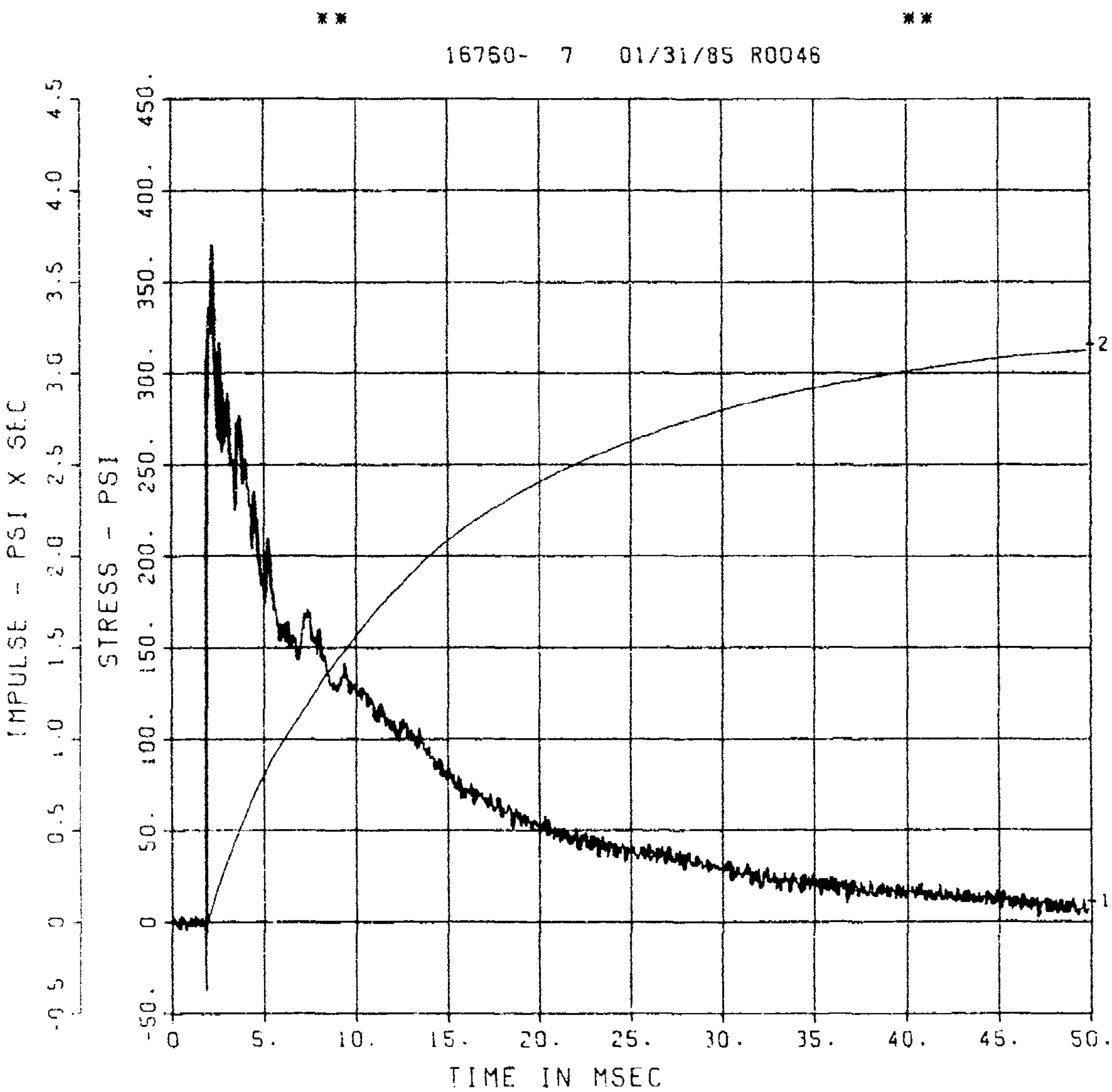
FEMA YIELD EFFECTS 4
BP-5
200000. HZ CAL= 1316.



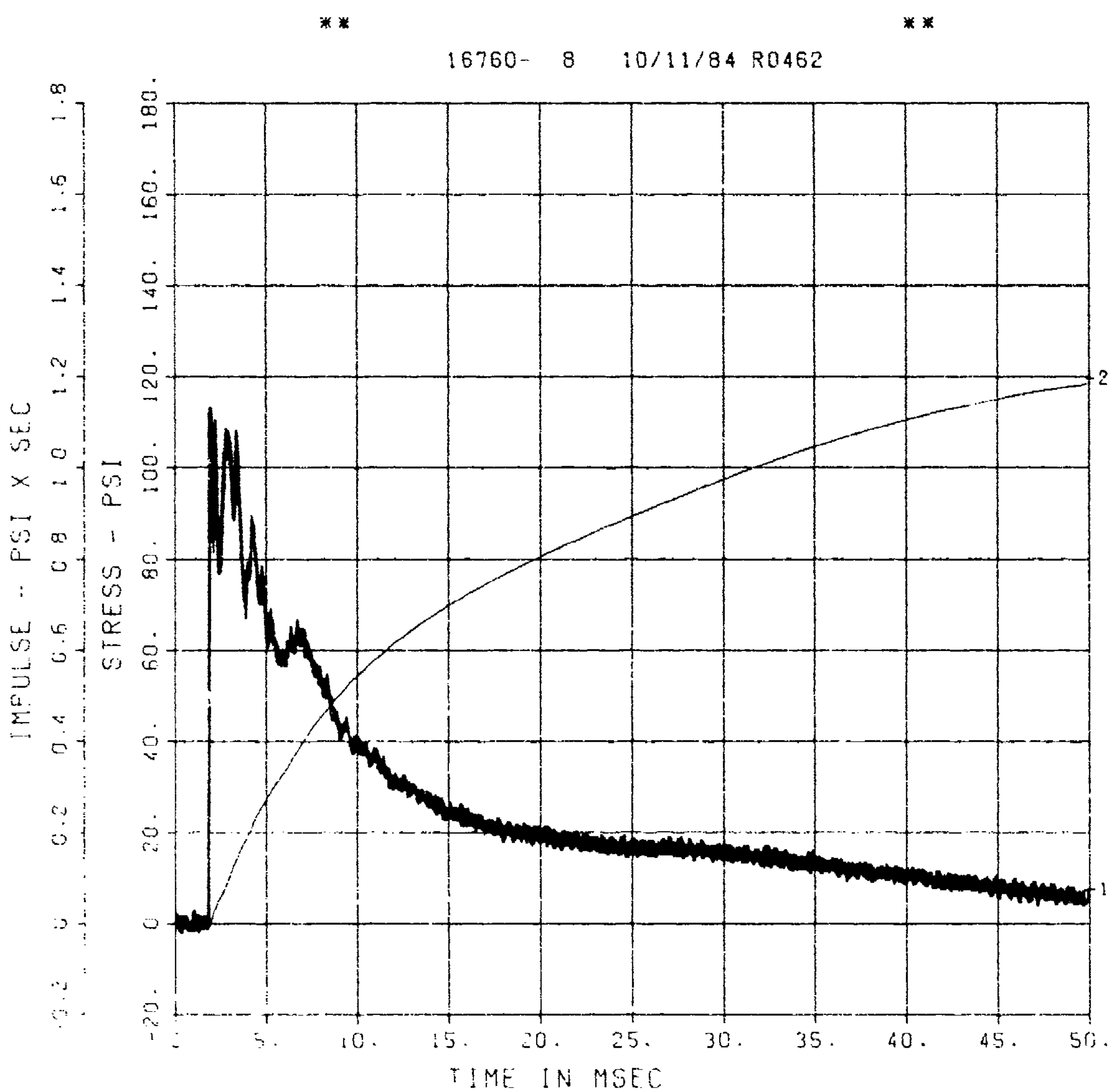
FEMA YIELD EFFECTS 4
BP-6
200000. HZ CAL= 1550.



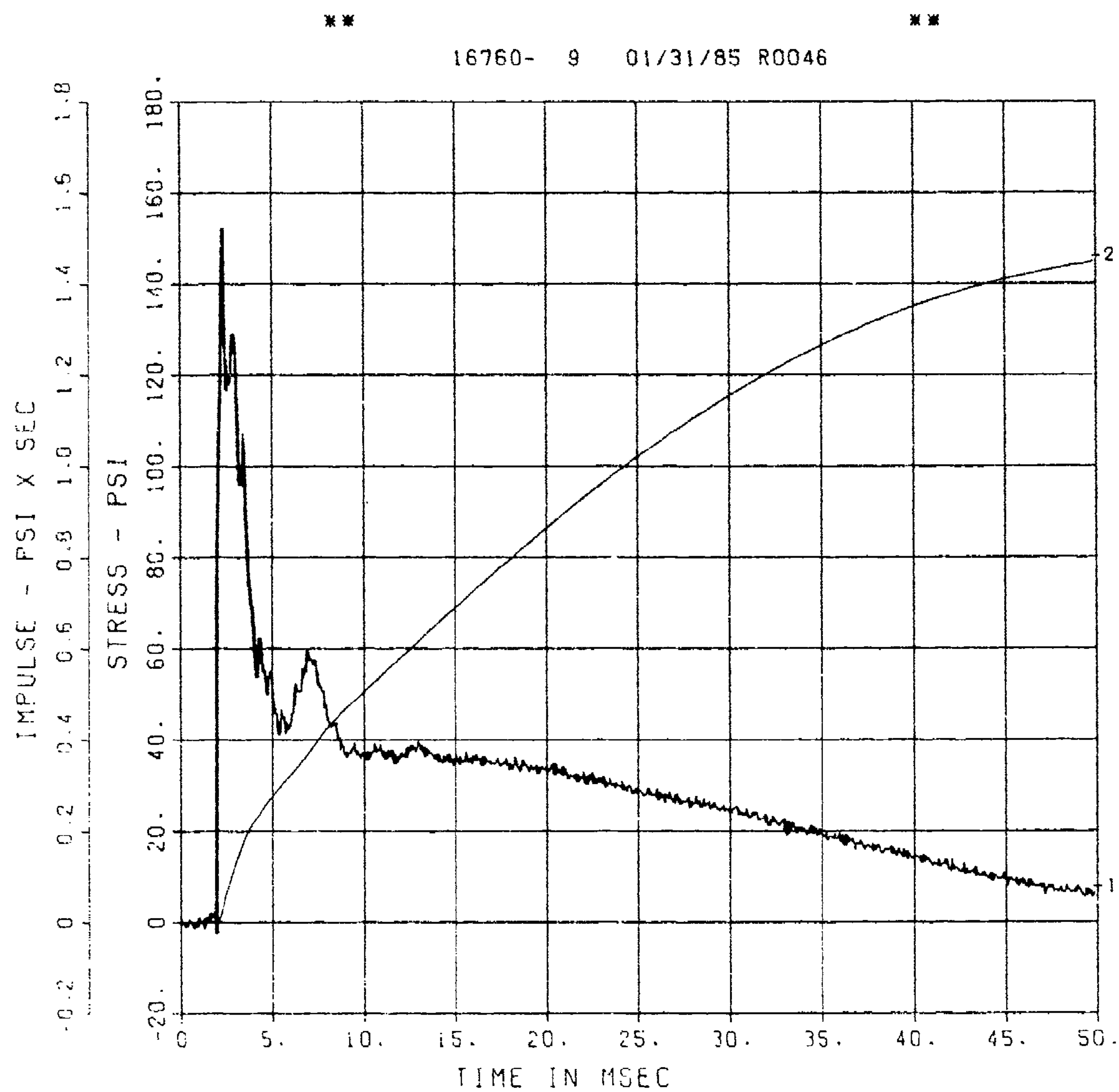
FEMA YIELD EFFECTS 4
SE-1
200000. HZ CAL= 1407.
LP2/0 70% CUTOFF= 18000. HZ



FEMA YIELD EFFECTS 4
SE-2
200000. HZ CAL= 345.0



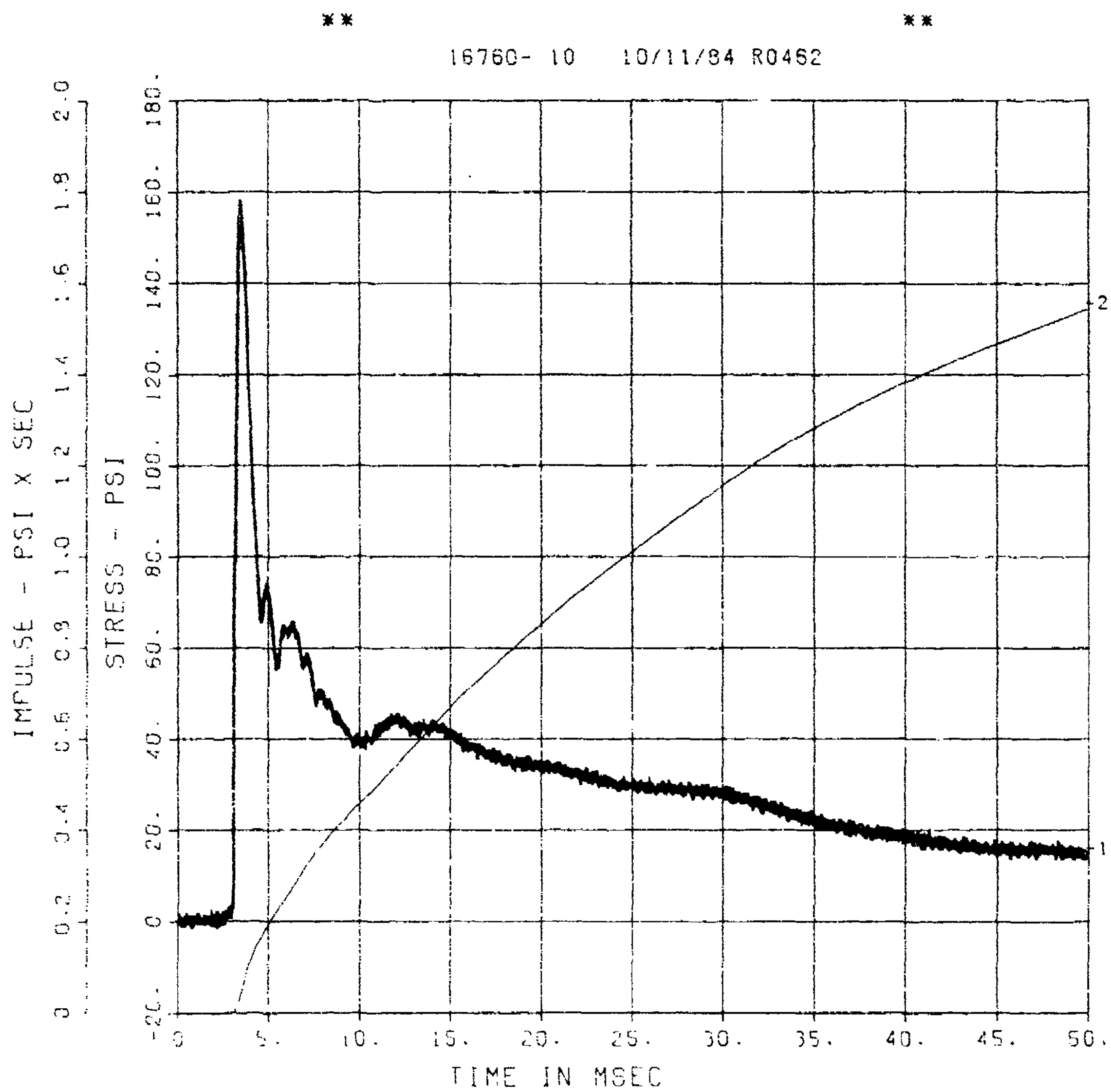
FEMA YIELD EFFECTS 4
SE-3
200000. HZ CAL= 311.0
LP2/0 70% CUTOFF= 18000. HZ



FEMA YIELD EFFECTS 4

SE-4

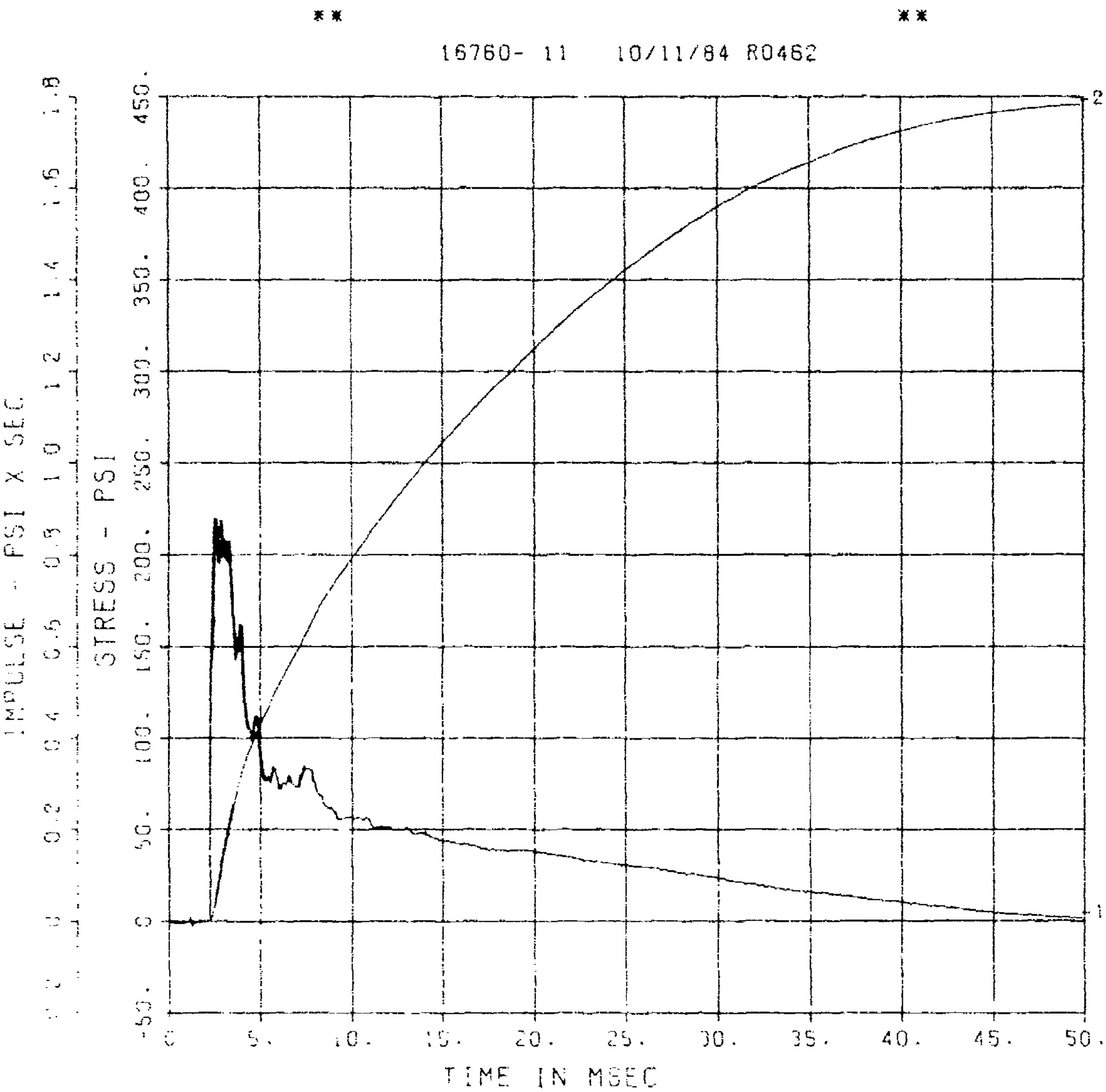
200000. HZ CAL= 244.0



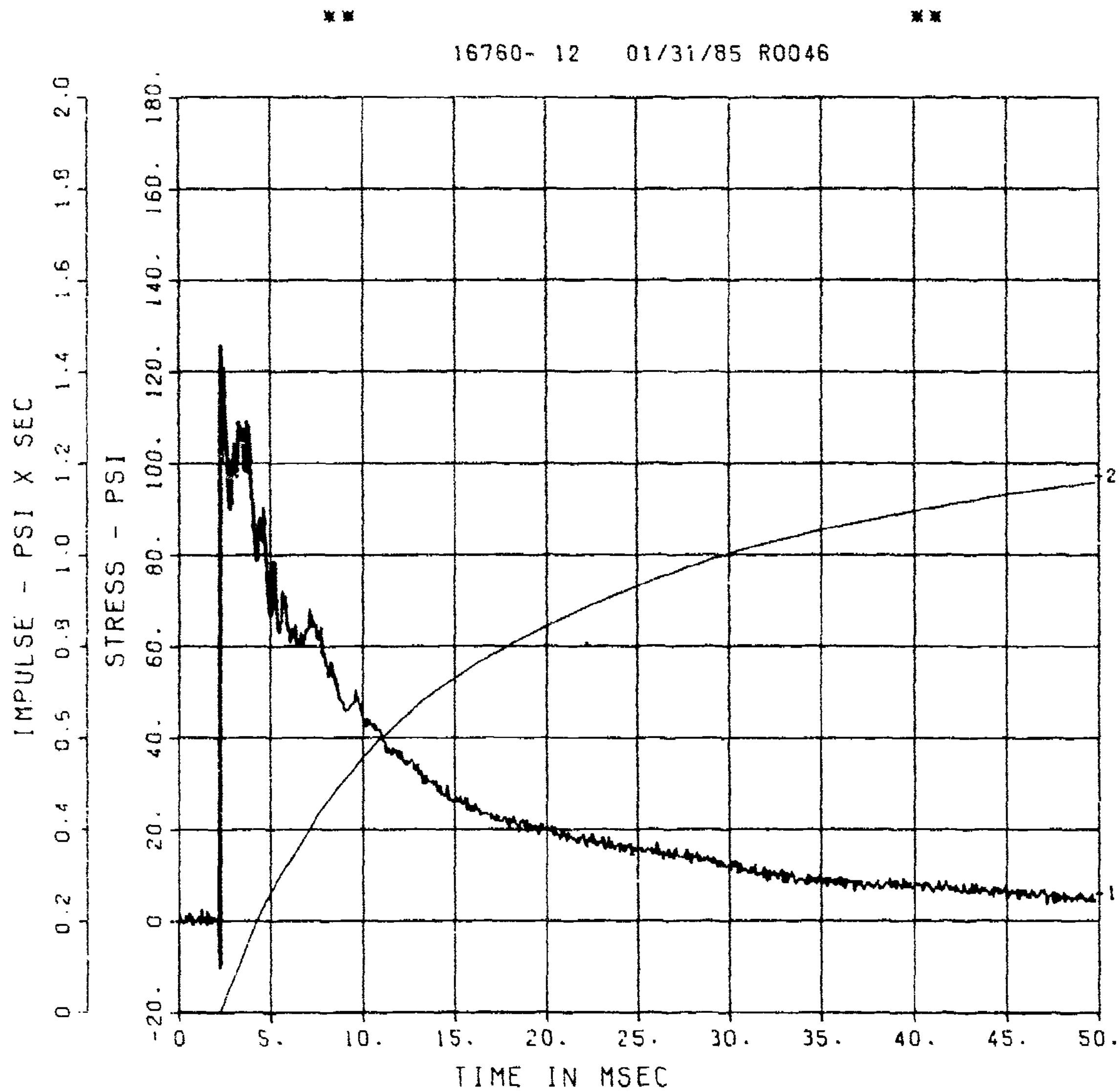
FEMA YIELD EFFECTS 4

SE-5

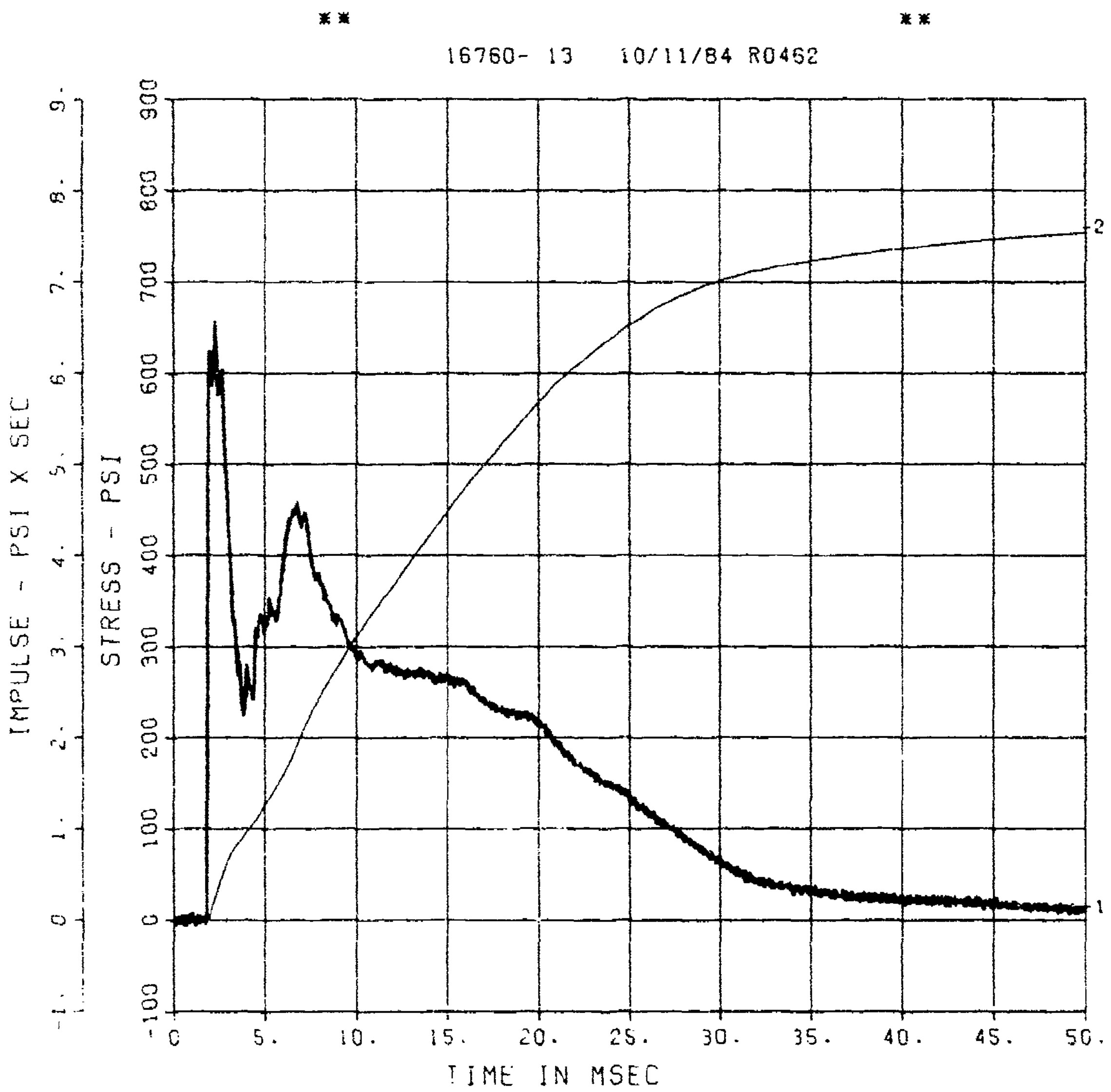
200000. HZ CAL= 133.0



FEMA YIELD EFFECTS 4
SE-6
200000. HZ CAL= 372.0
LP2/0 70% CUTOFF= 18000. HZ



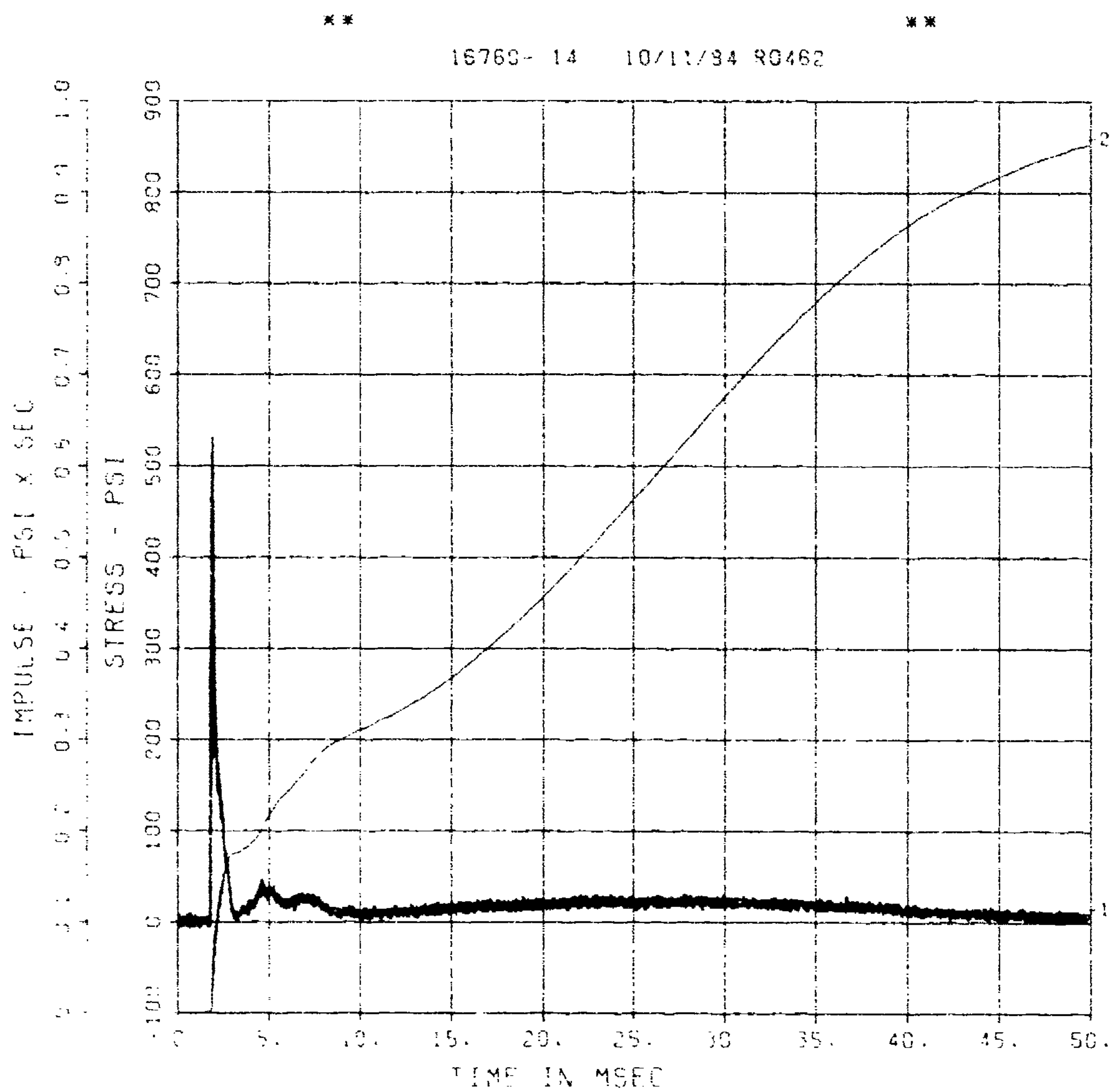
FEMA YIELD EFFECTS 4
SE-7
200000. HZ CAL= 768.0



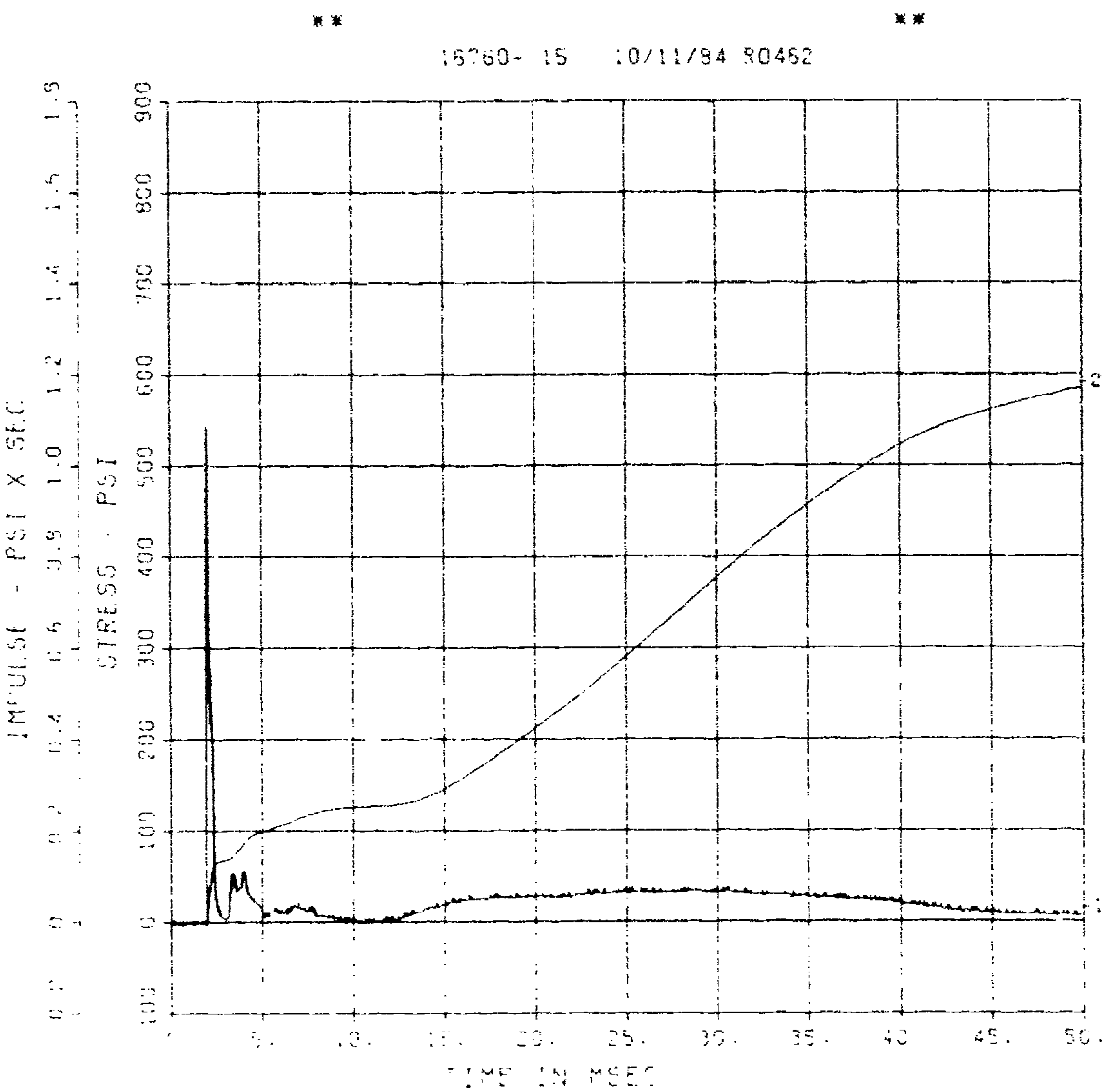
FEMA YIELD EFFECTS 4

SE-8

200000. HZ CAL= 778.0



FEMA YIELD EFFECTS 4
SE-9
200000. HZ CAL= 529.0

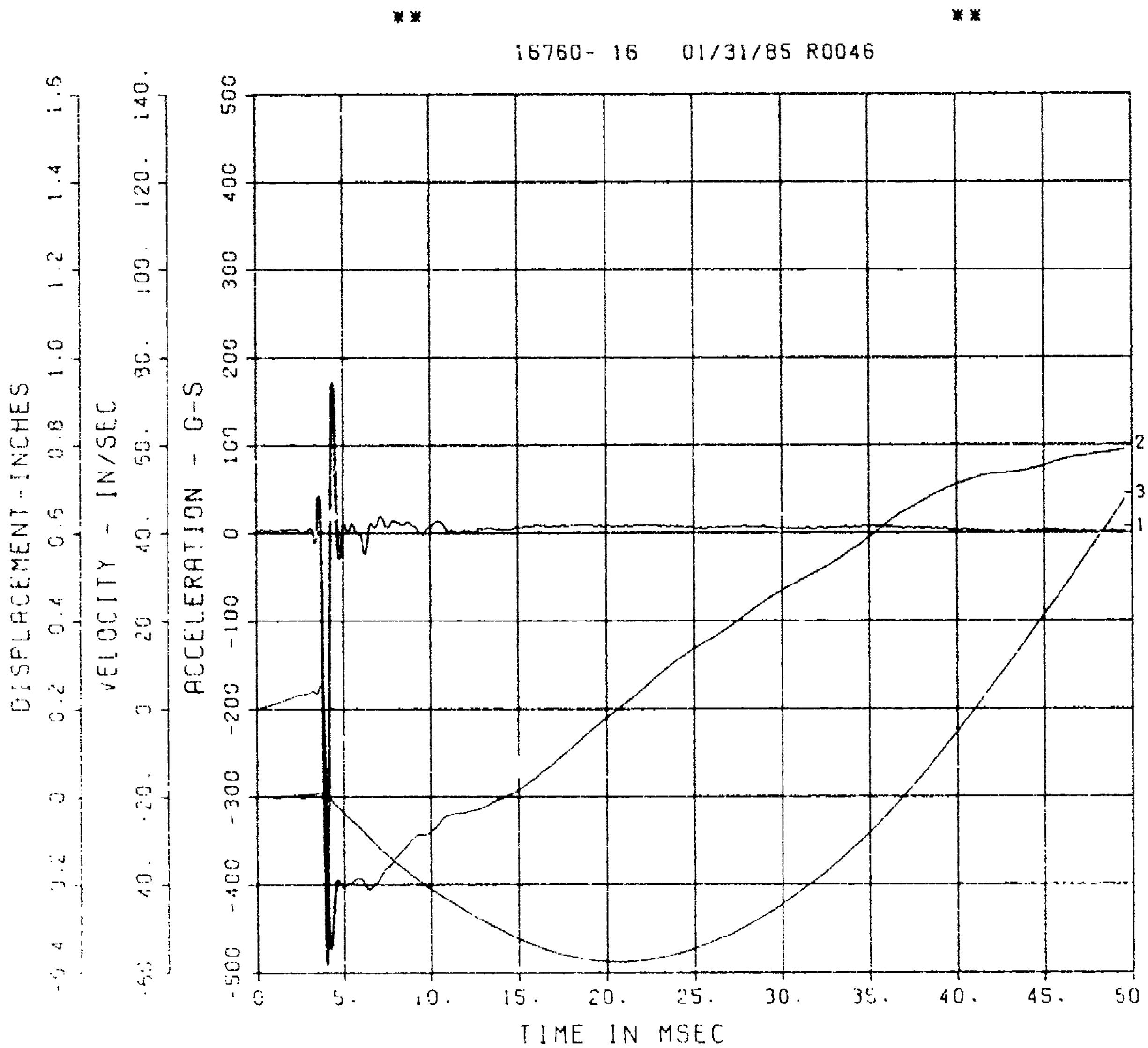


FEMA YIELD EFFECTS 4

AFF-1

50000. HZ CAL= 1096.

LP4/4 70% CUTOFF= 2250. HZ

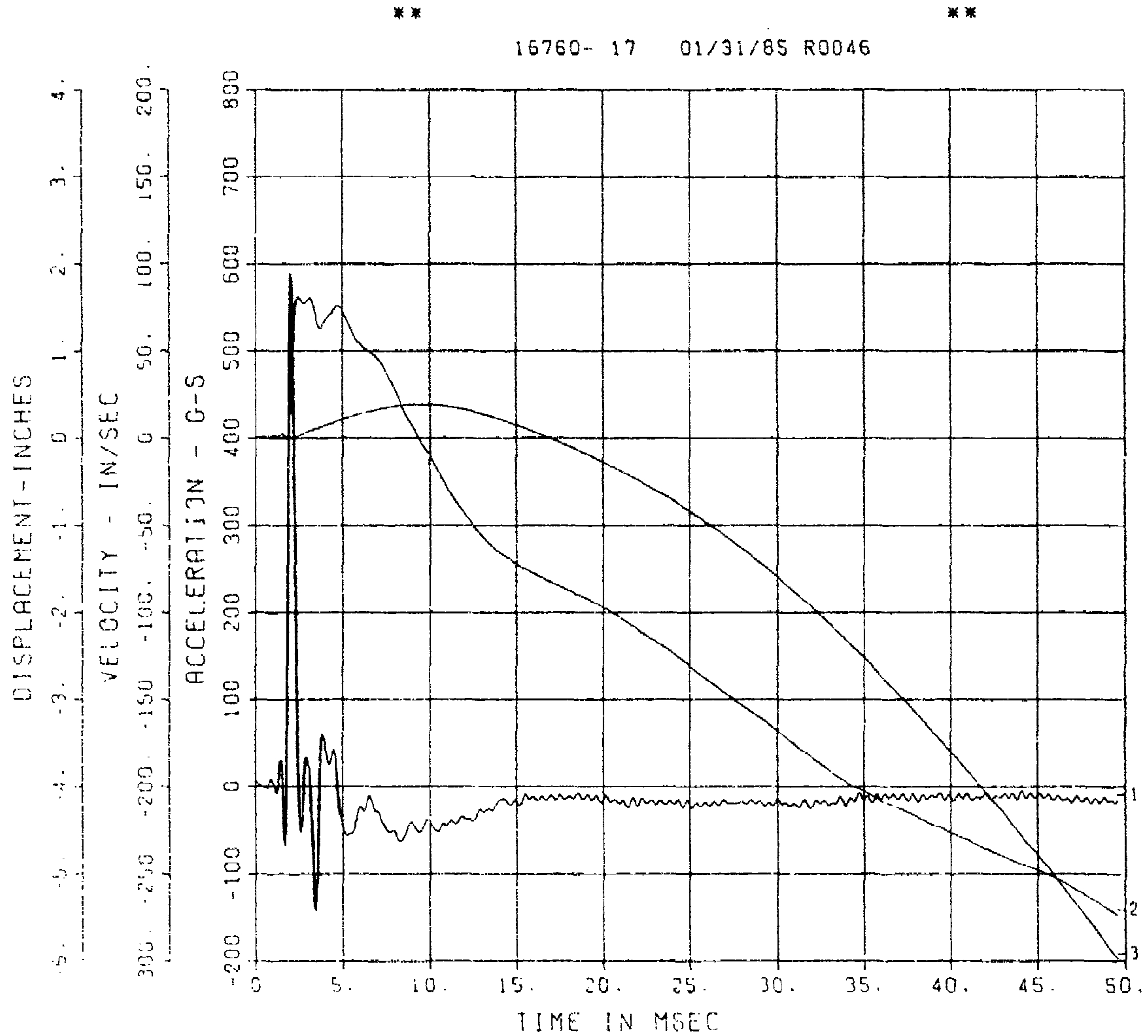


FEMA YIELD EFFECTS 4

A-1

50000. HZ CAL= 3671.

LP4/4 70% CUTOFF= 2250. HZ

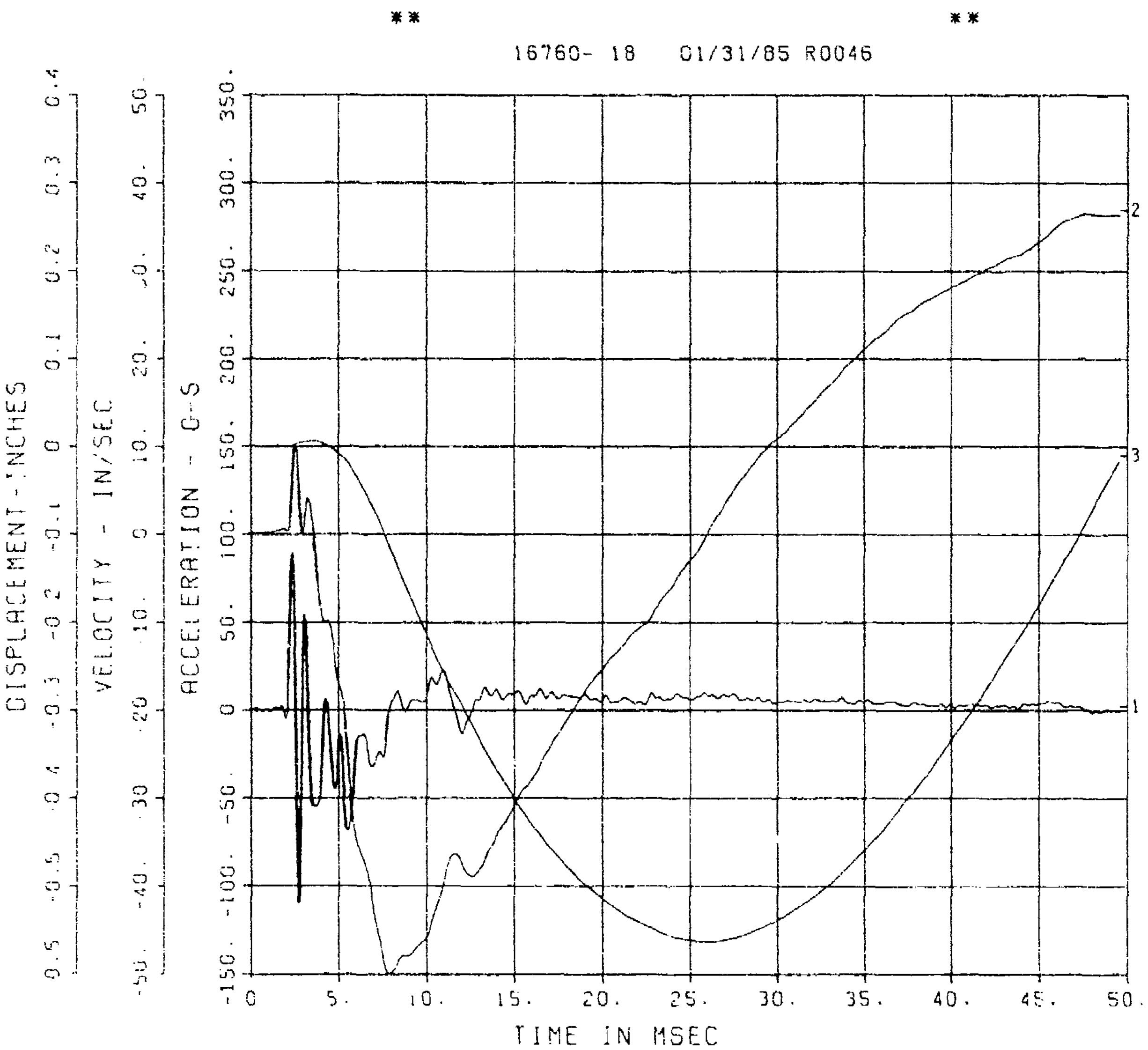


FEMA YIELD EFFECTS 4

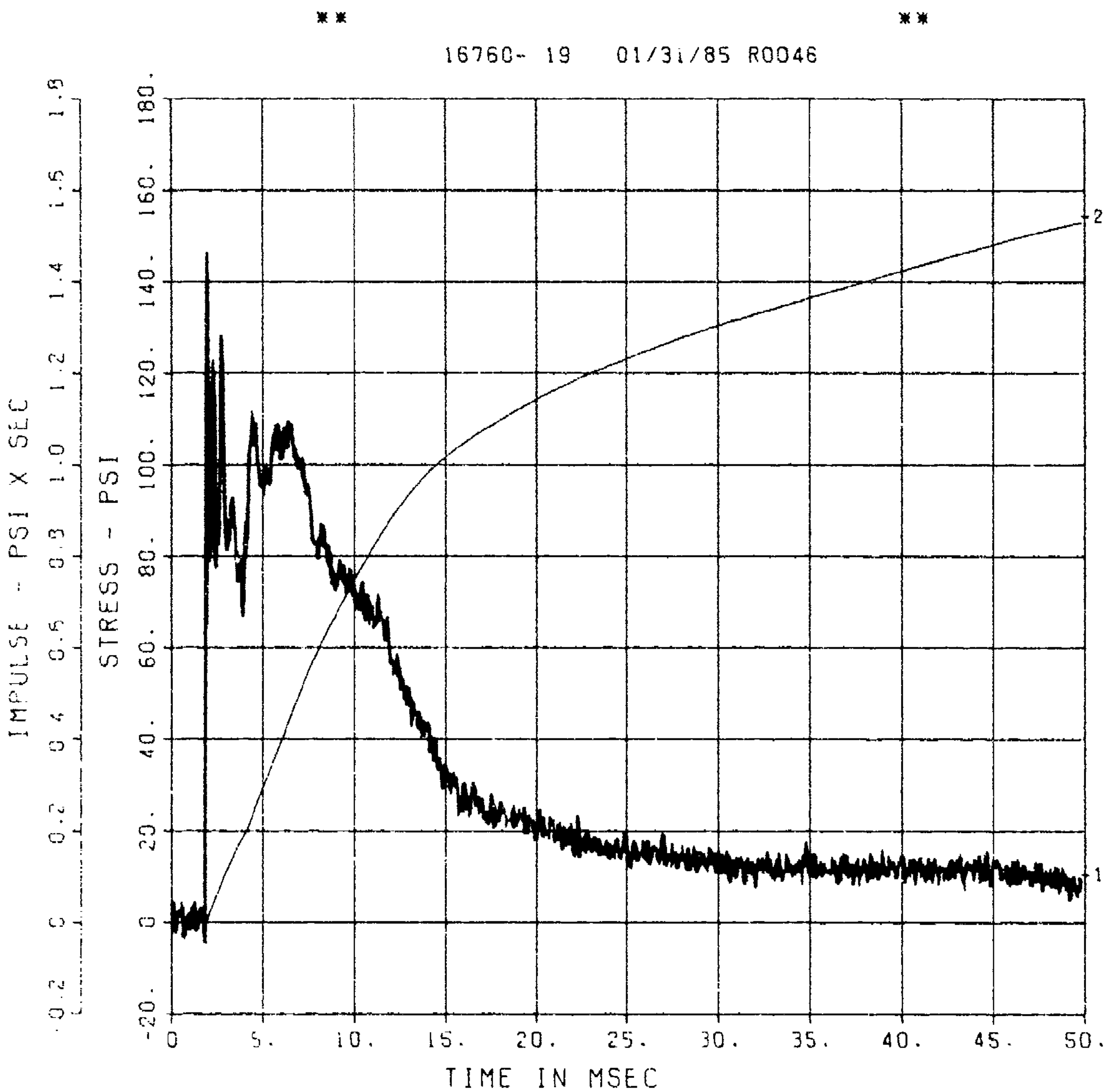
A-2

50000. HZ CAL= 640.0

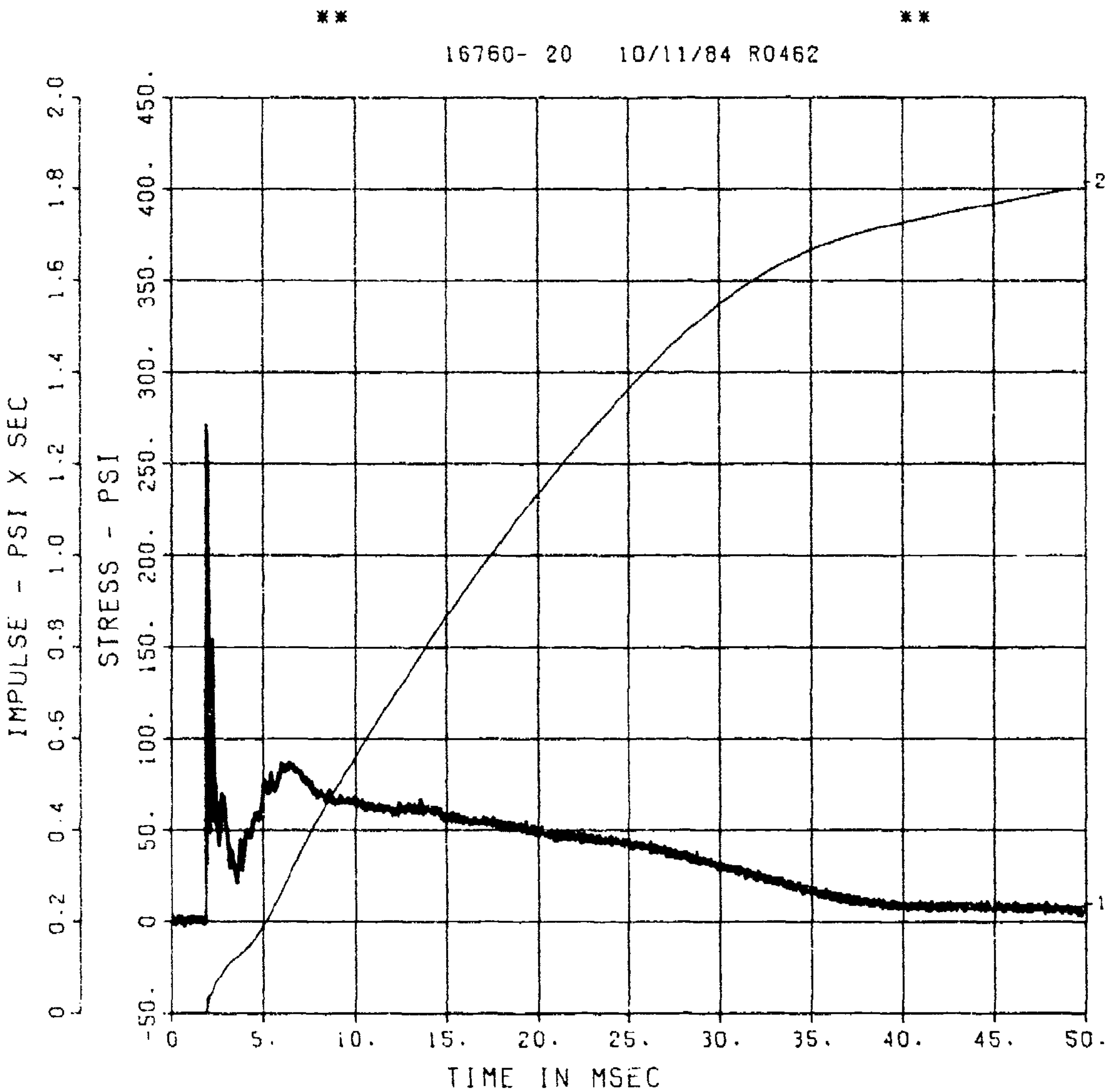
LP4/4 70% CUTOFF= 2250. HZ



FEMA YIELD EFFECTS 4
IF-1
200000. HZ CAL= 785.0
LP2/0 70% CUTOFF= 18000. HZ



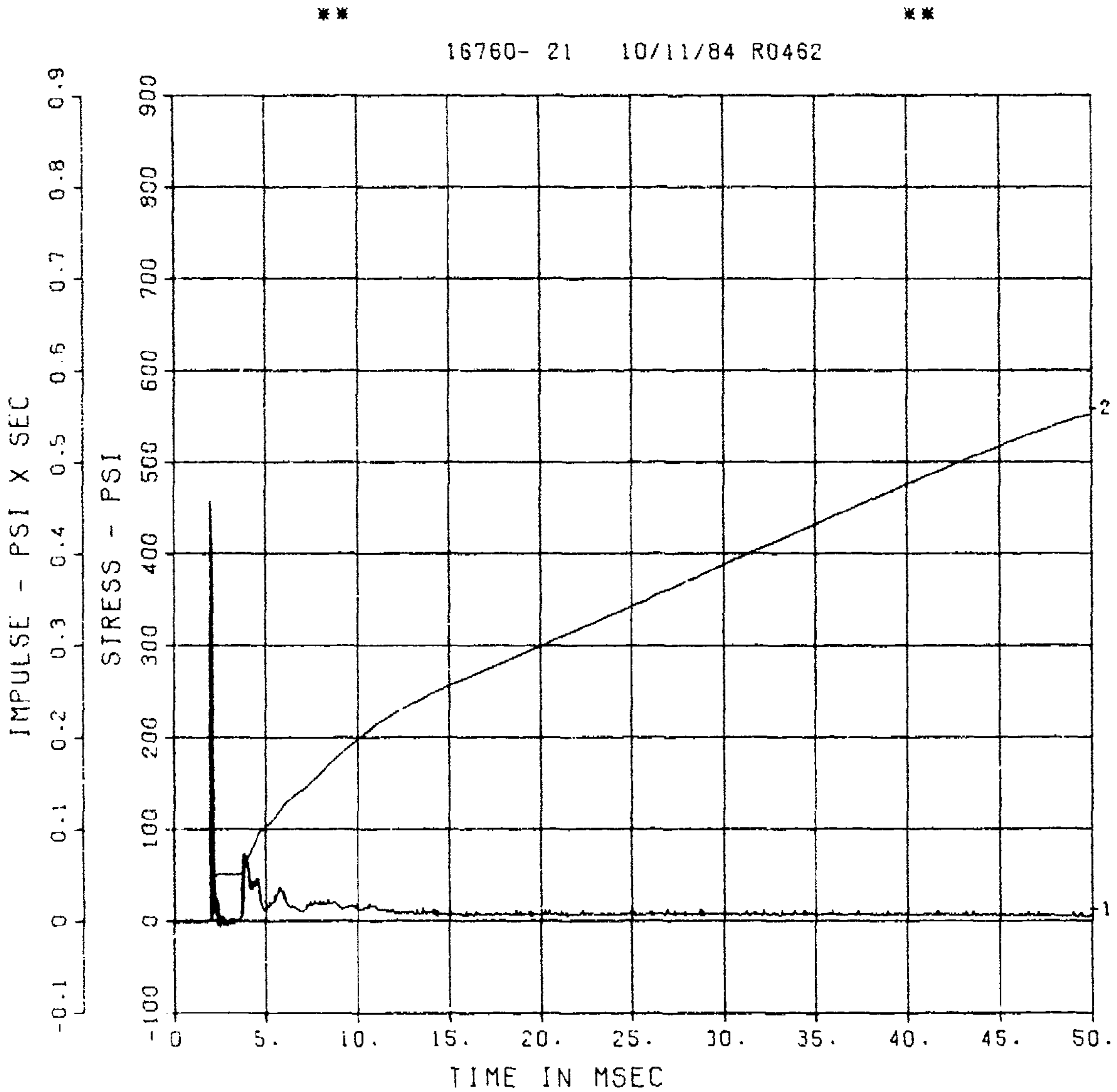
FEMA YIELD EFFECTS 4
IF-2
200000. HZ CAL= 397.0



FEMA YIELD EFFECTS 4

IF-3

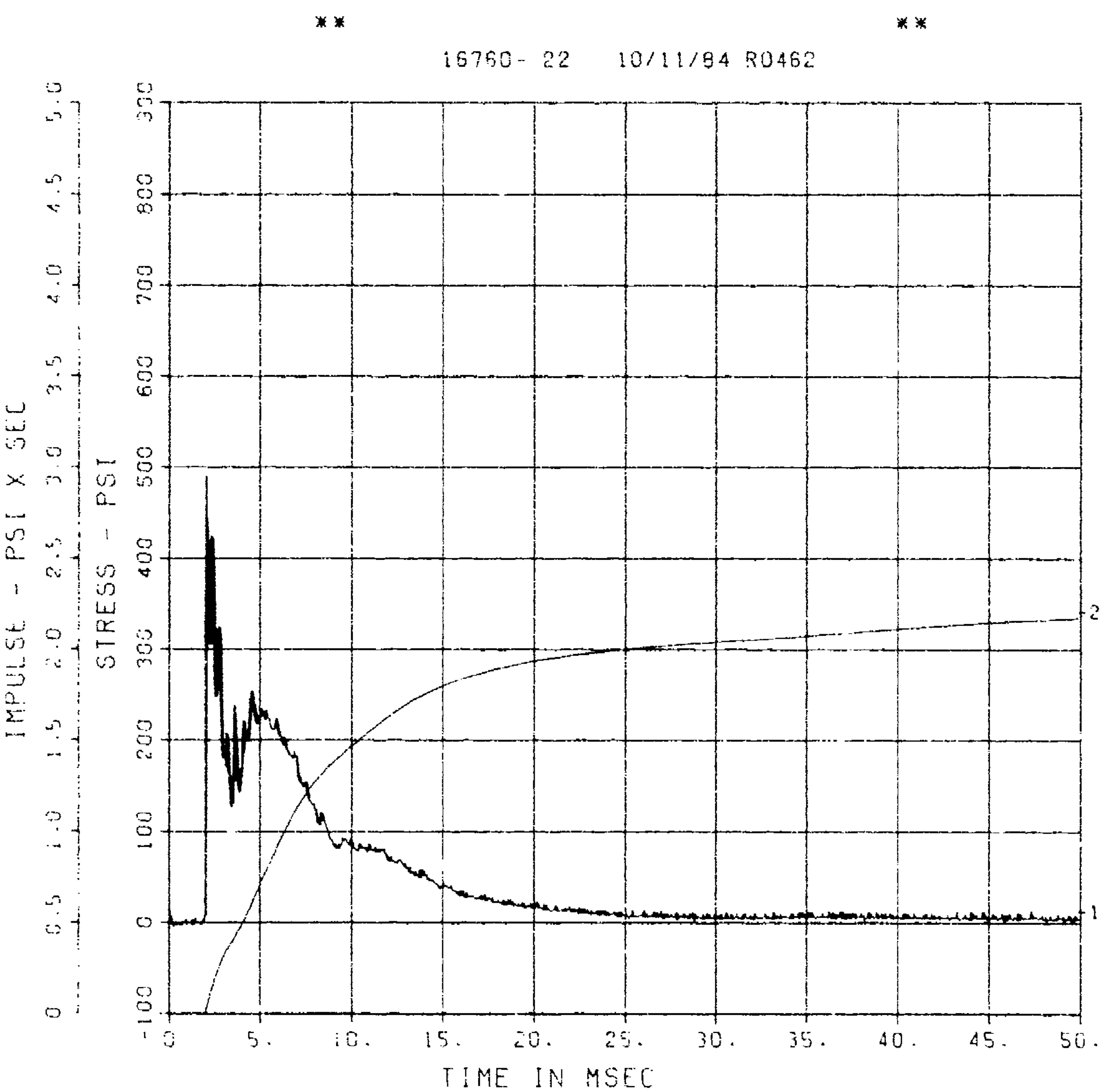
200000. HZ CAL= 381.0



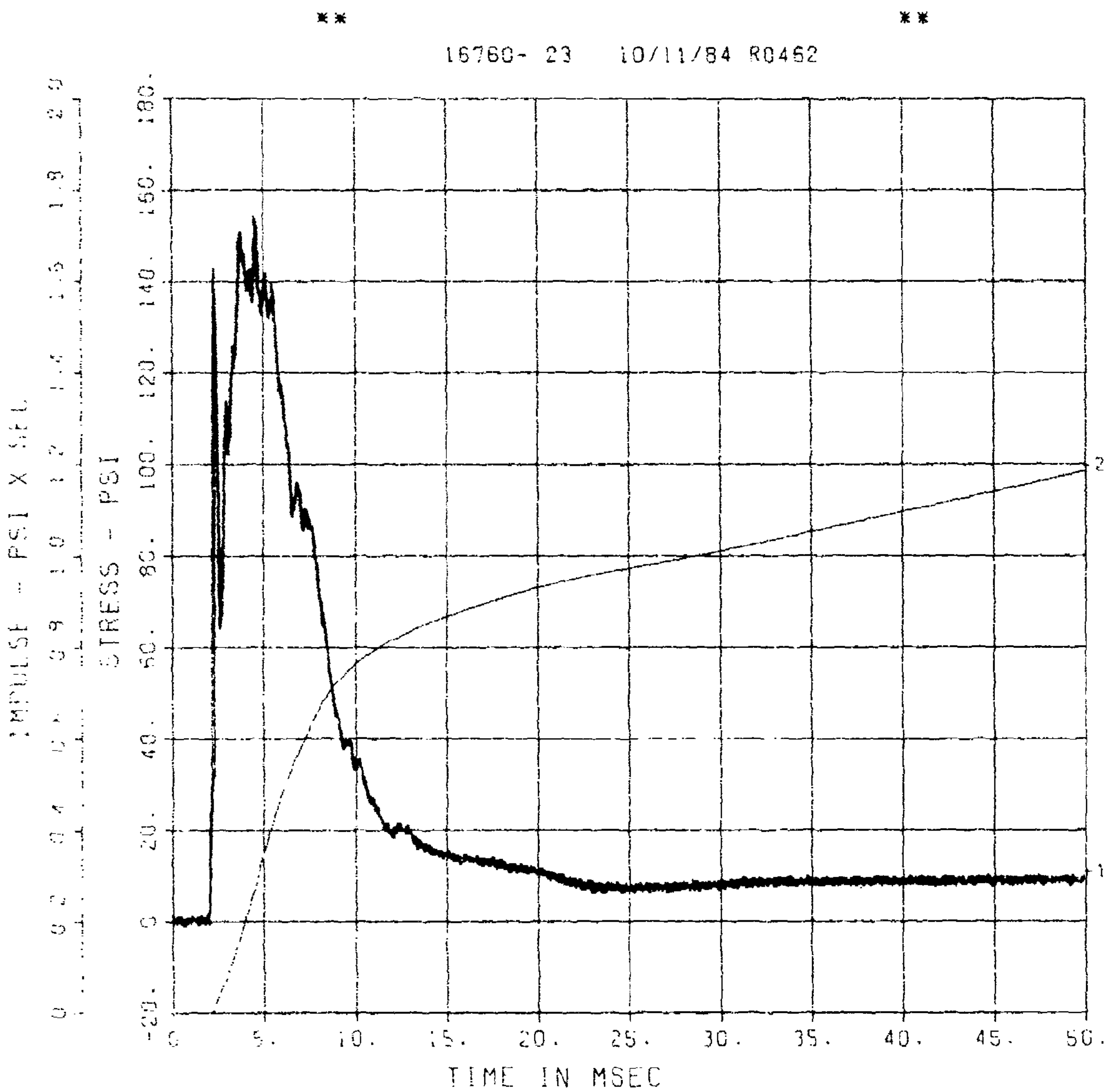
FEMA YIELD EFFECTS 4

IF-4

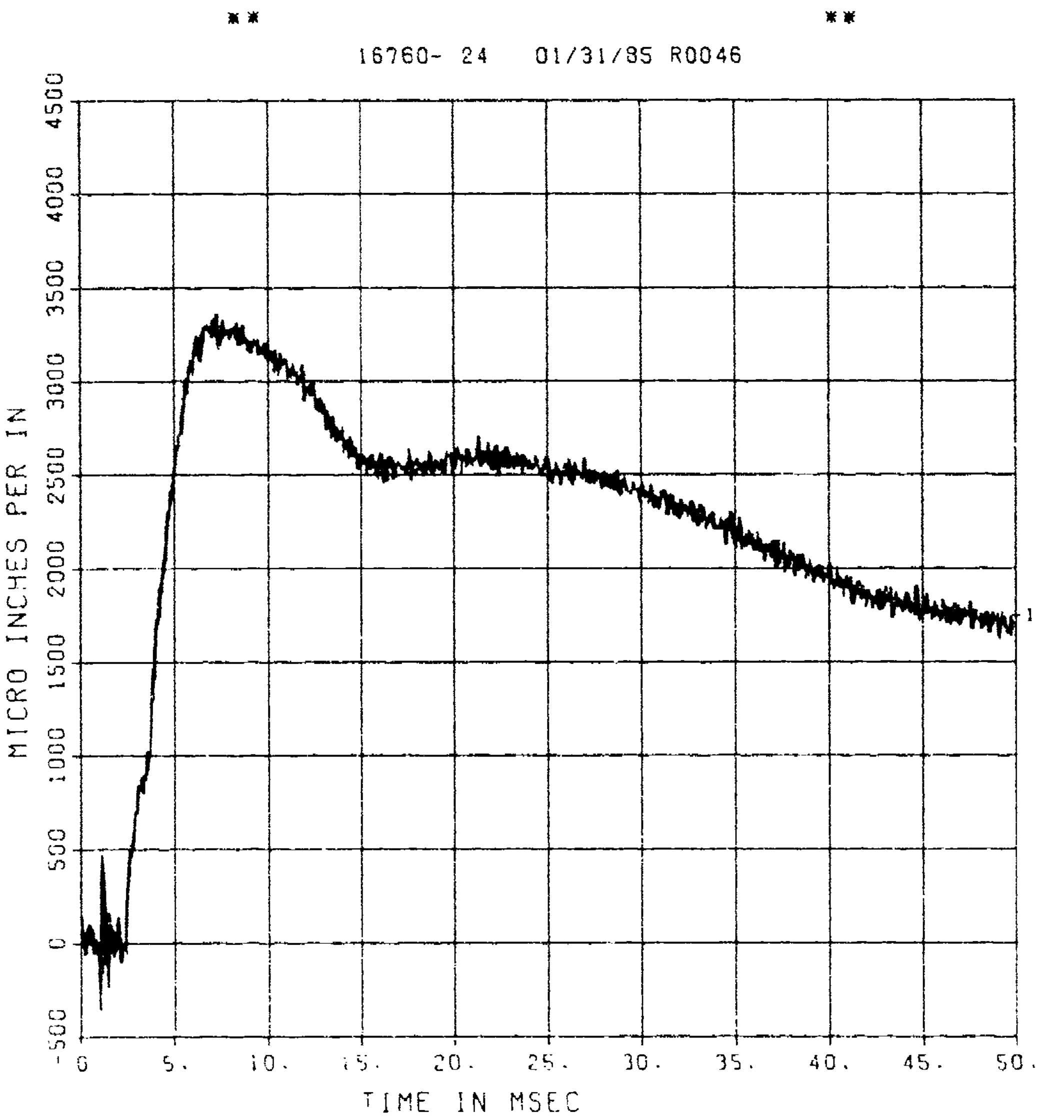
200000. HZ CAL= 501.0



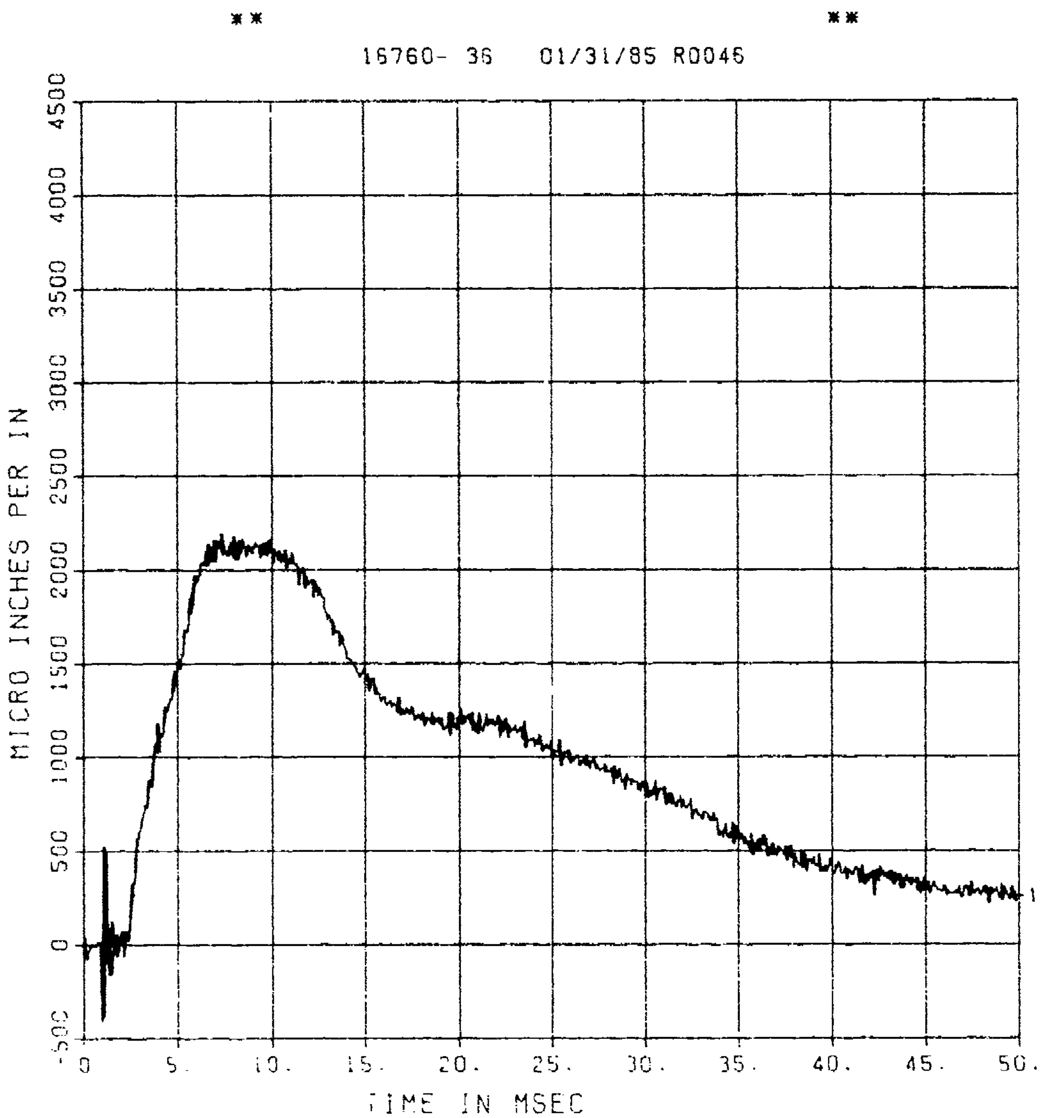
FEMA YIELD EFFECTS 4
IF-5
200000. HZ CAL= 155.0



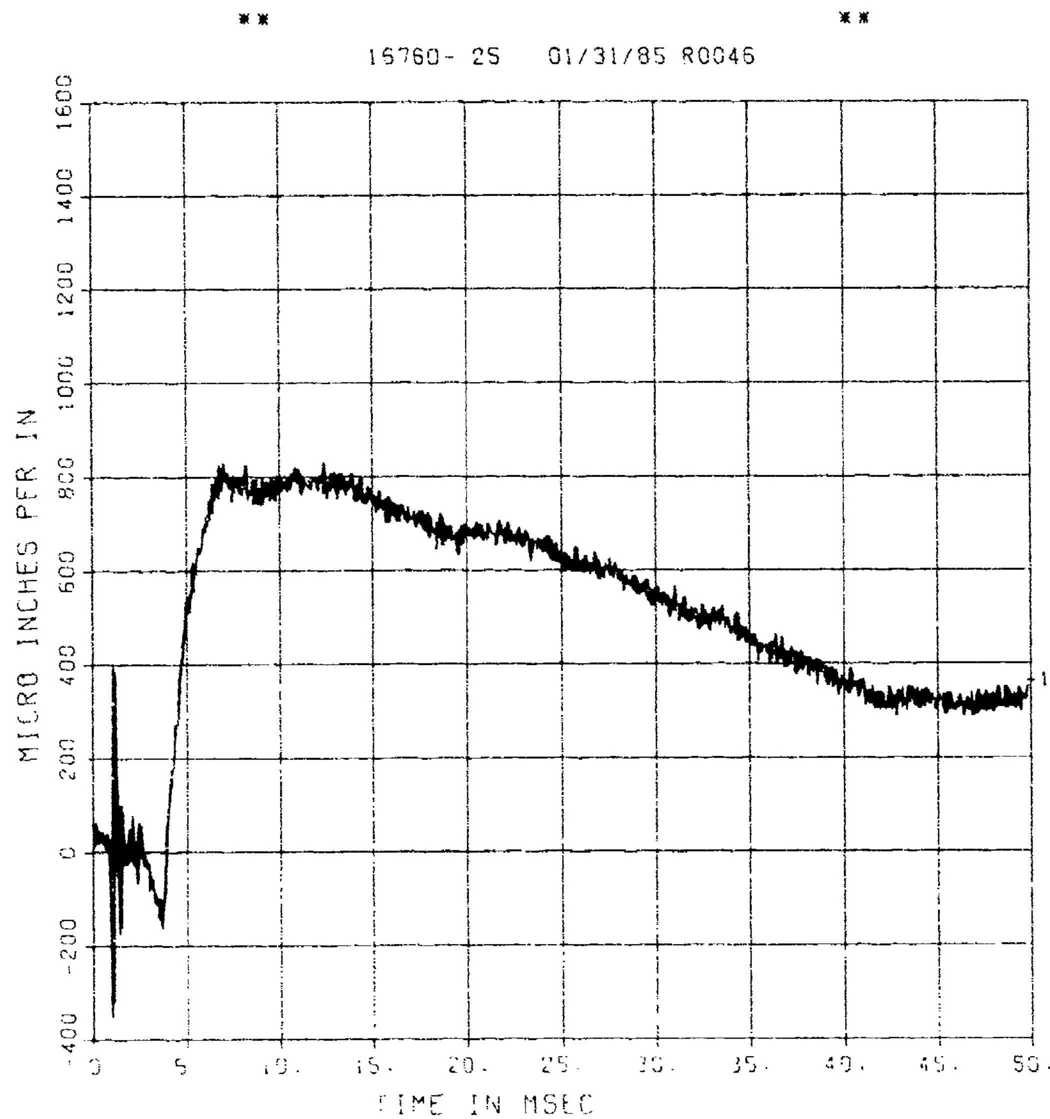
FEMA YIELD EFFECTS 4
EO-1
200000. HZ CAL= 19670.
LP2/0 70% CUTOFF= 18000. HZ



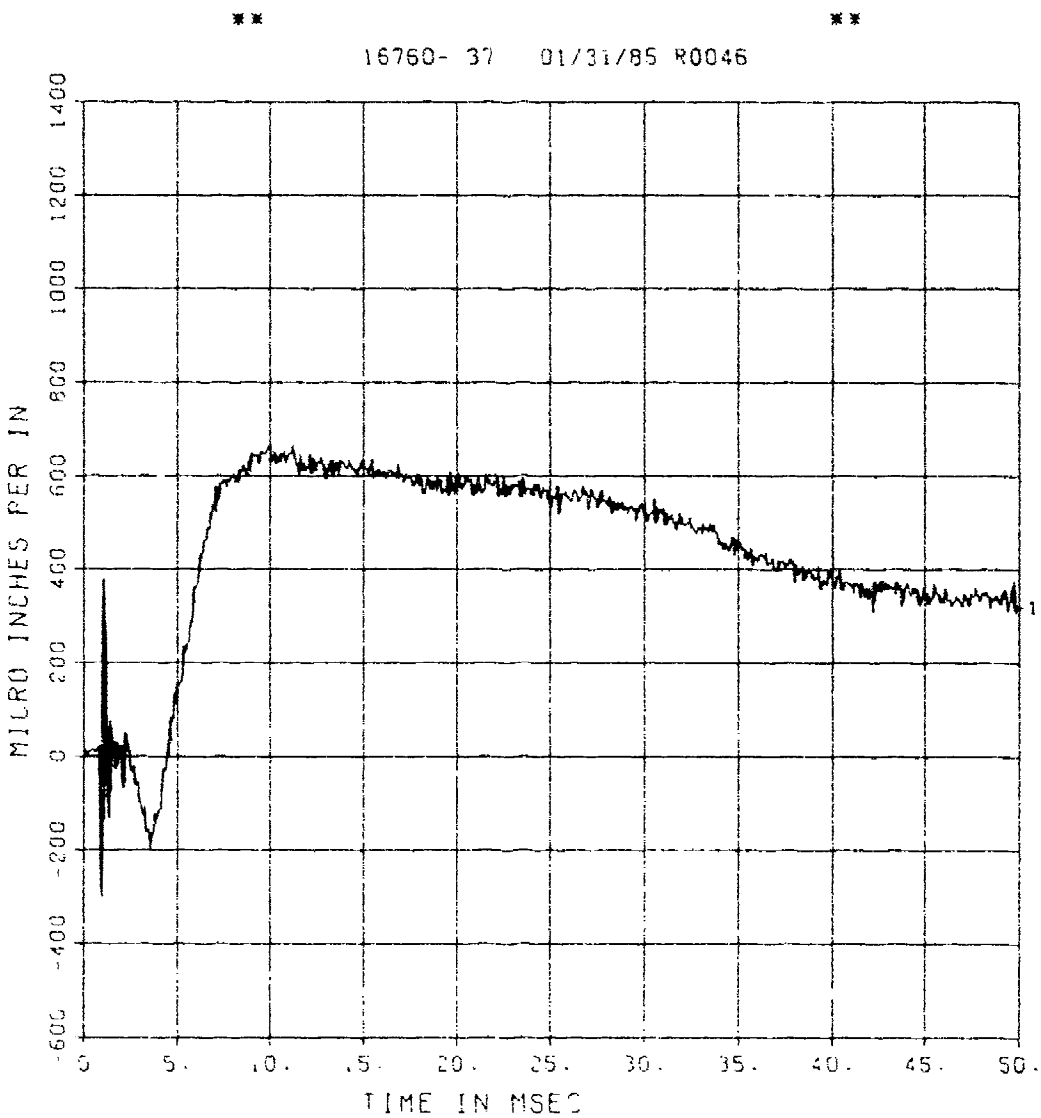
FEMA YIELD EFFECTS 4
EO-1A
200000. HZ CAL= 19670.
LP4/0 70% CUTOFF= 9000. HZ



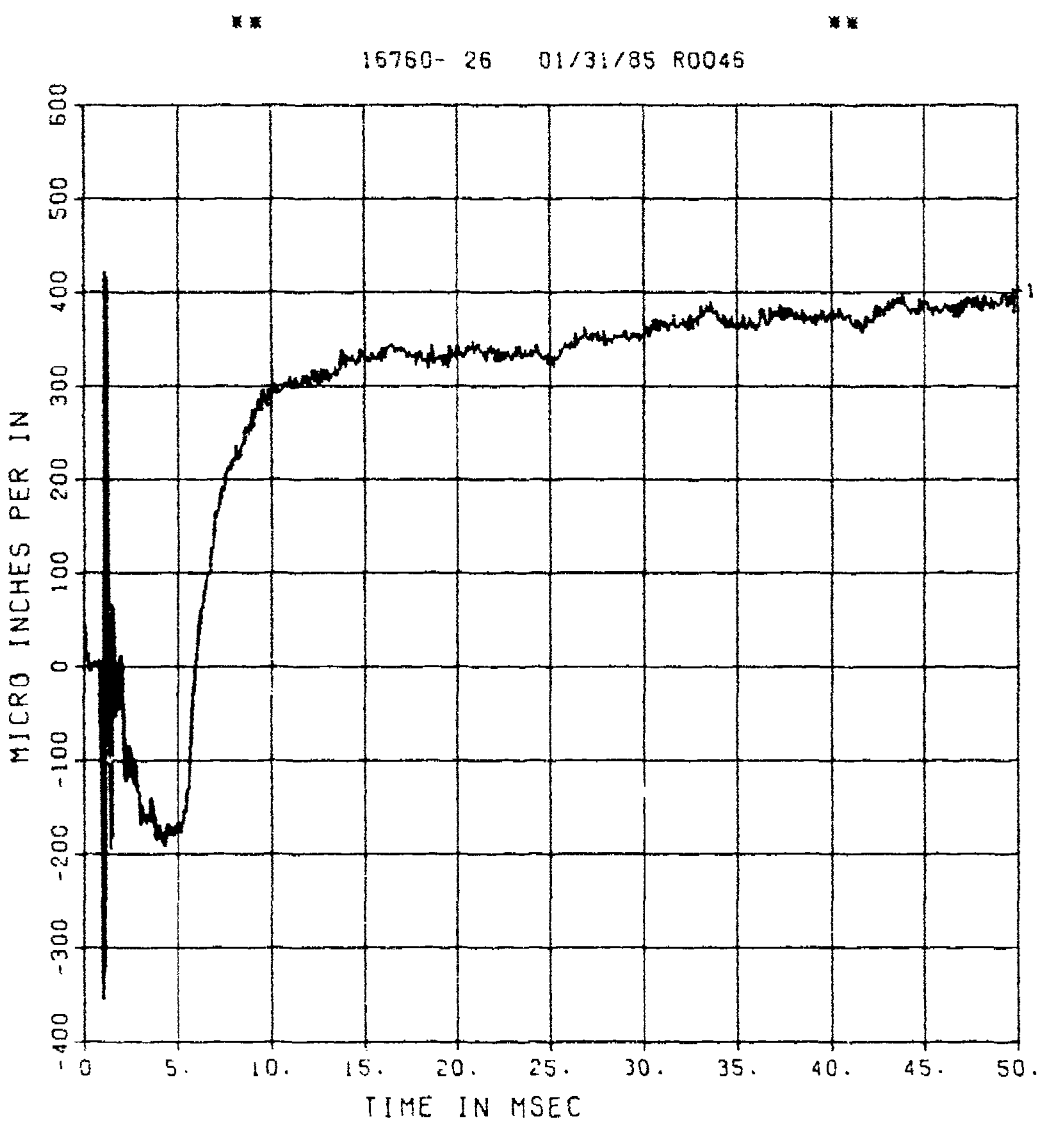
FEMA YIELD EFFECTS 4
EI-1
200000. HZ CAL= 6686.
LP2/0 70% CUTOFF= 18000. HZ



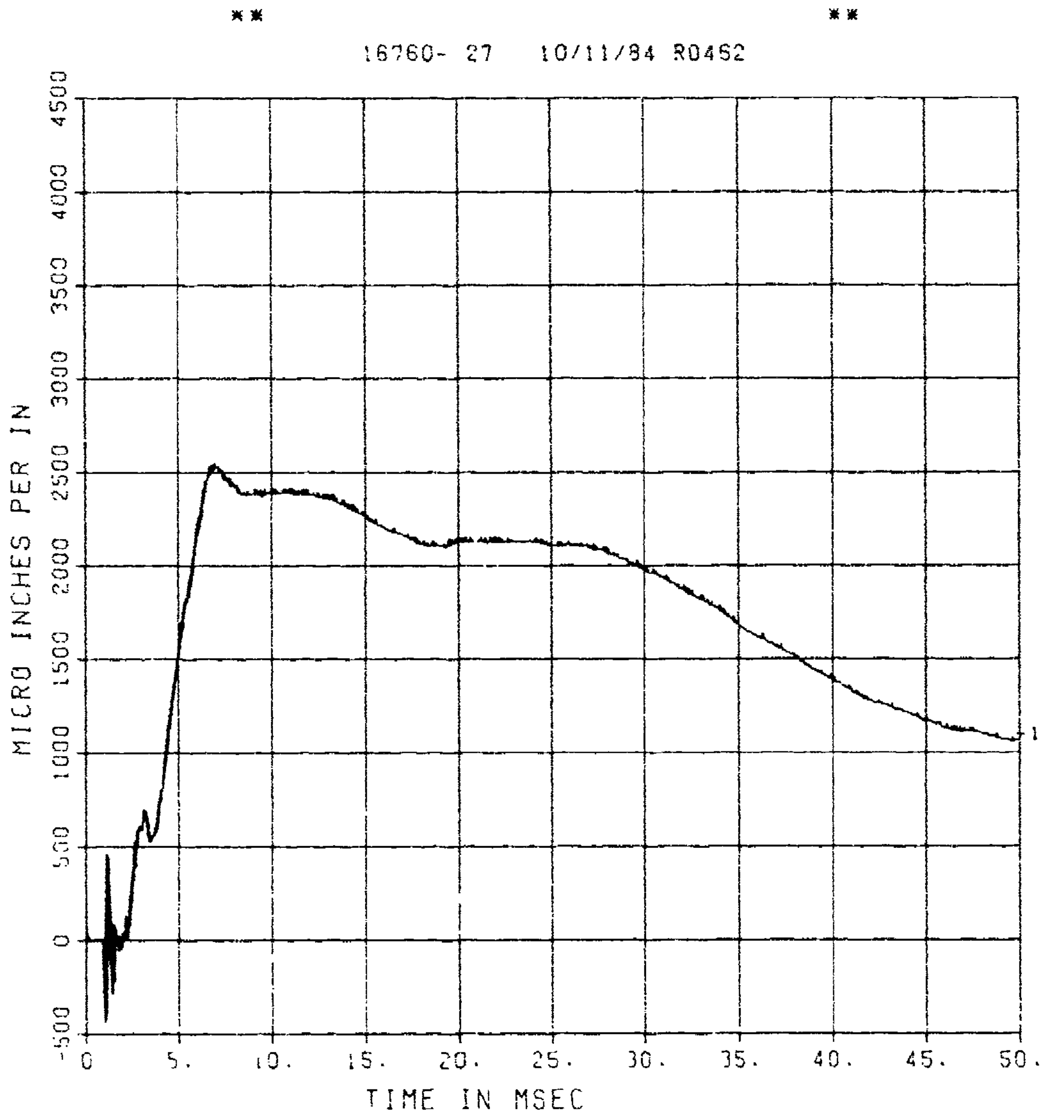
FEMA YIELD EFFECTS 4
EI-1A
200000. HZ CAL= 6686.
LP4/0 70% CUTOFF= 9000. HZ



FEMA YIELD EFFECTS 4
EO-2
200000. HZ   CAL= 2028.
LP2/0 70% CUTOFF= 18000. HZ



FEMA YIELD EFFECTS 4
EI-2
200000. HZ CAL= 2028.

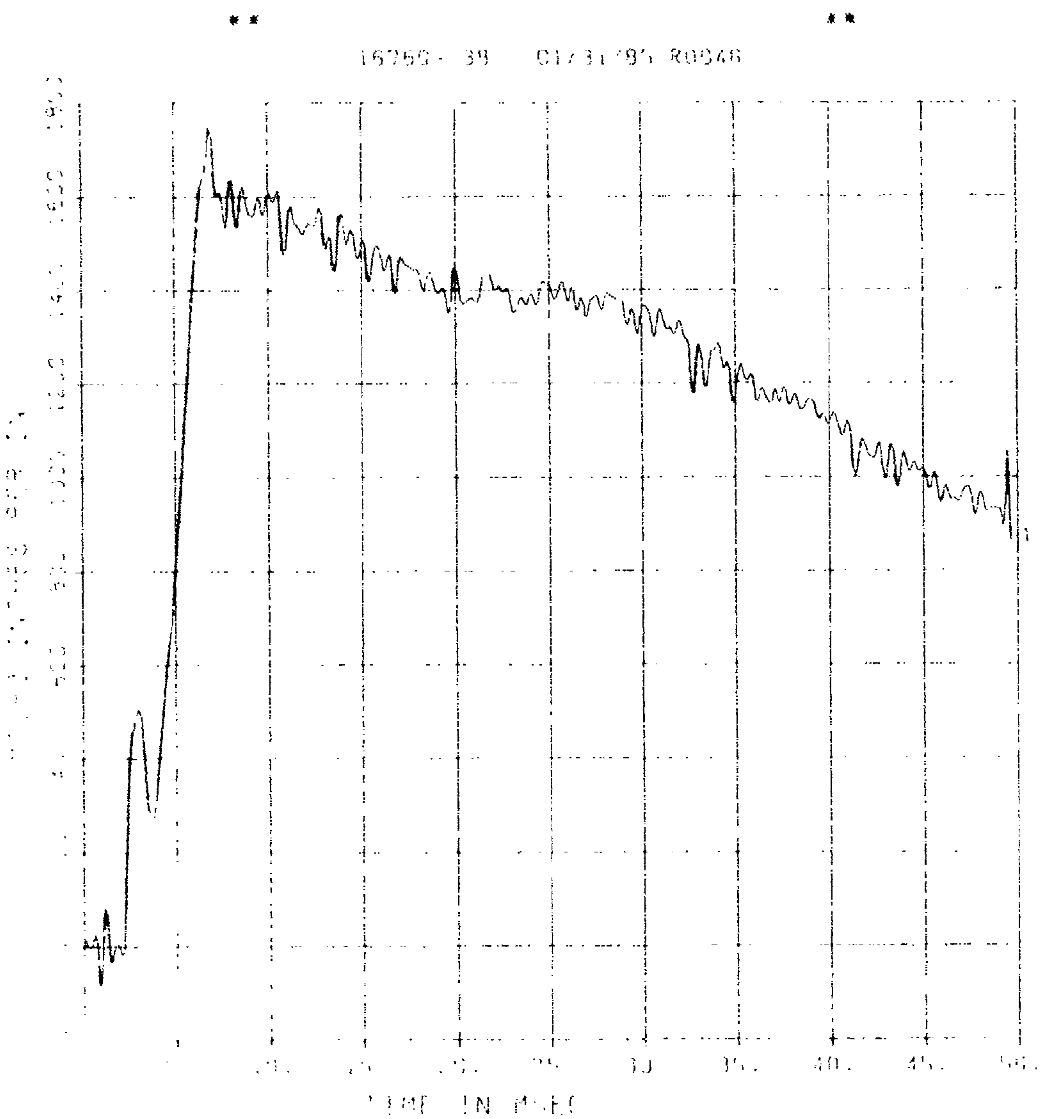


FEMA YIELD EFFECTS 4

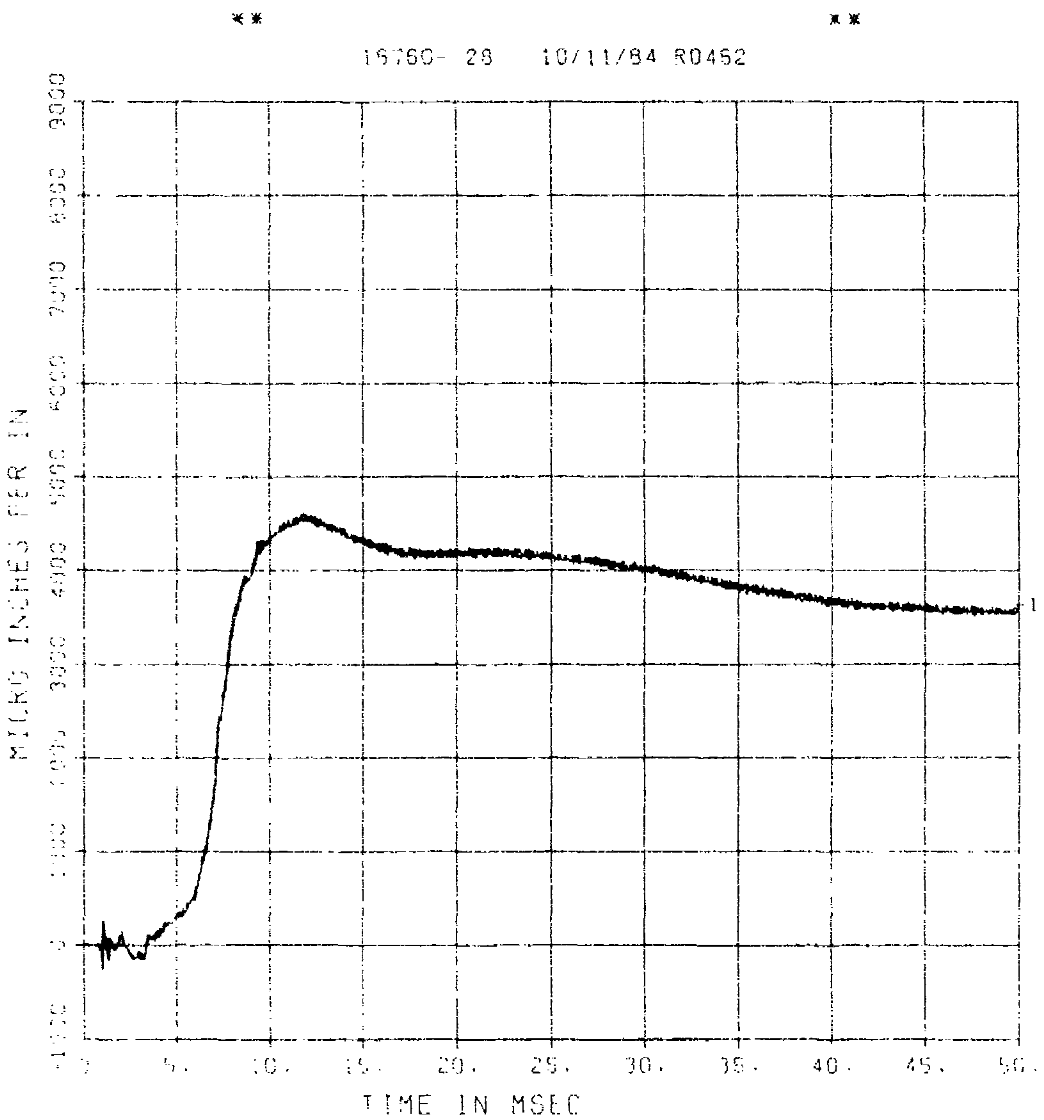
E1-2A

50000. HZ CAL= 2028.

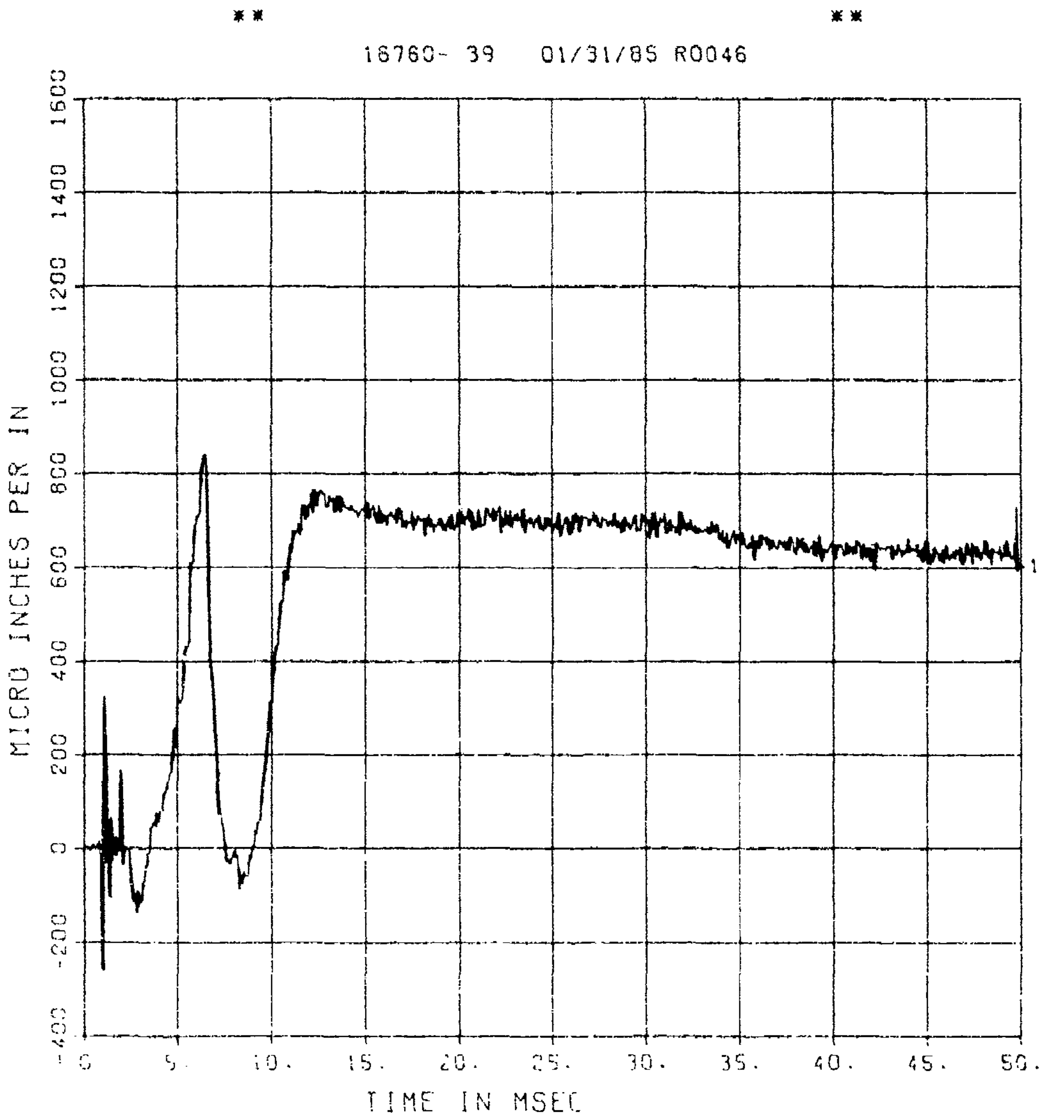
LP4/4 70% CUTOFF 2250. HZ



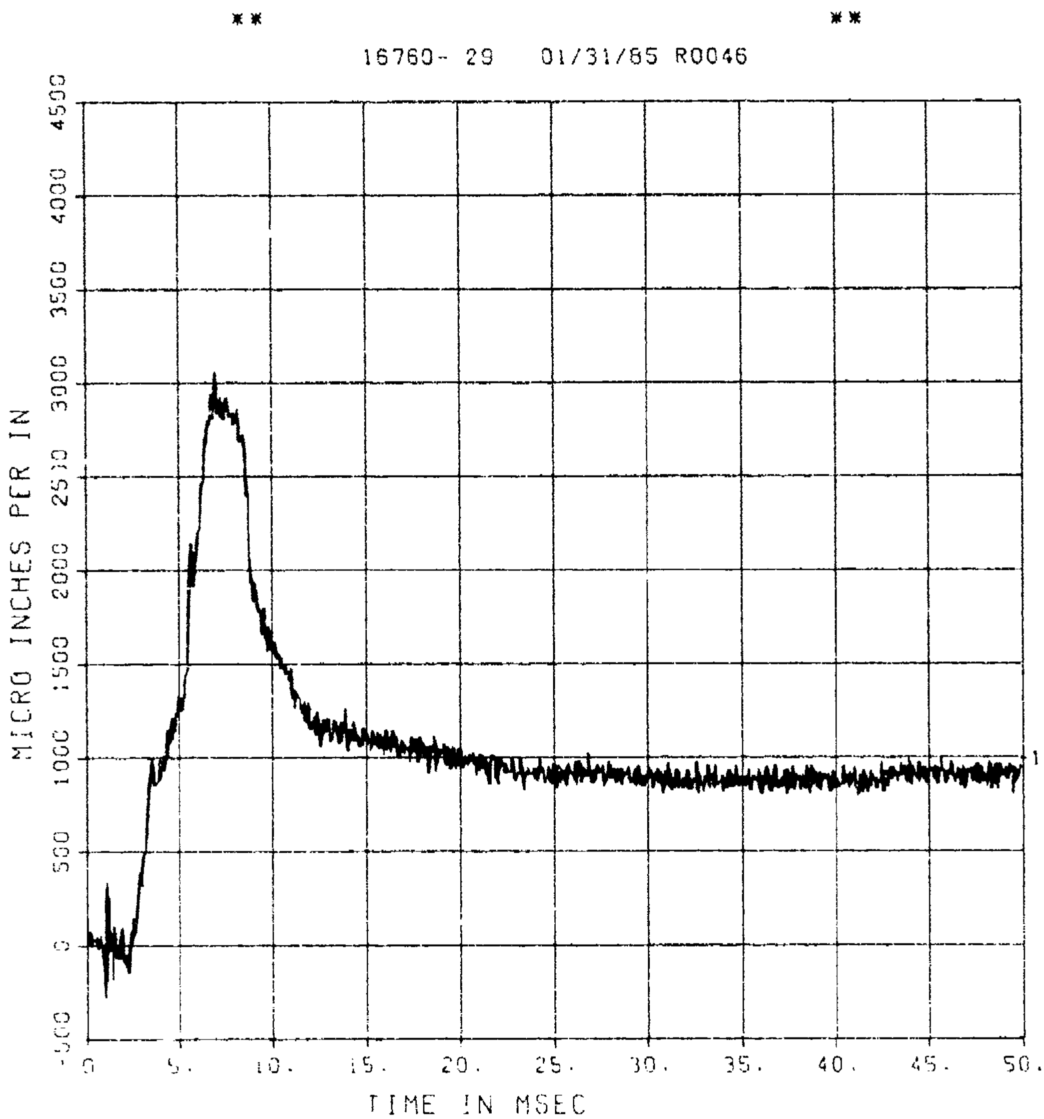
FEMA YIELD EFFECTS 4
EO-3
200000. HZ CAL= 6686.



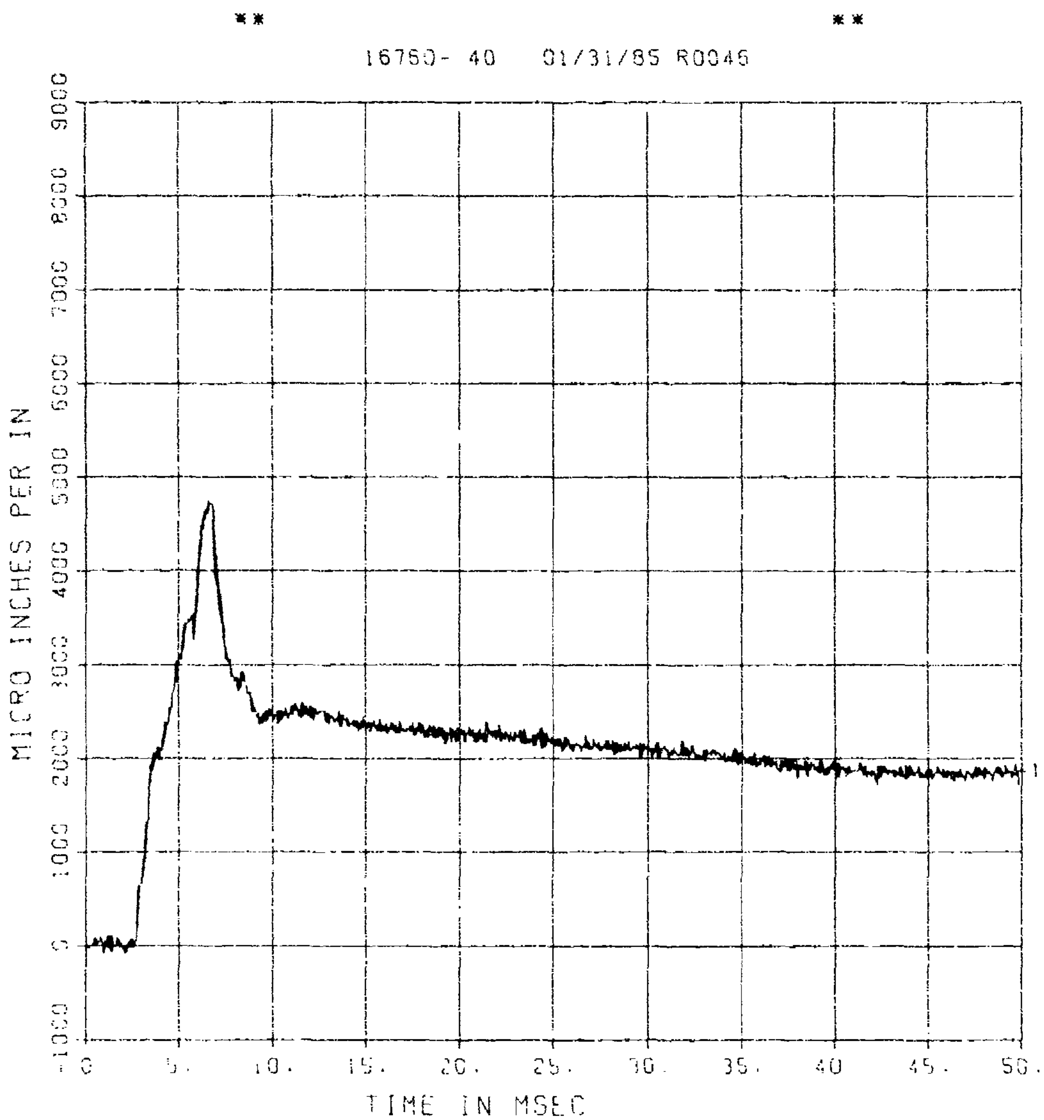
FEMA YIELD EFFECTS 4
E0-3A
200000. HZ CAL= 6686.
LP4/0 70% CUTOFF= 9000. HZ



FEMA YIELD EFFECTS 4
EI-3
200000. HZ CAL= 19670.
LP2/0 70% CUTOFF= 18000. HZ



FEMA YIELD EFFECTS 4
EI-3A
200000. HZ CAL= 19670.
LP2/O 70% CUTOFF= 18000. HZ

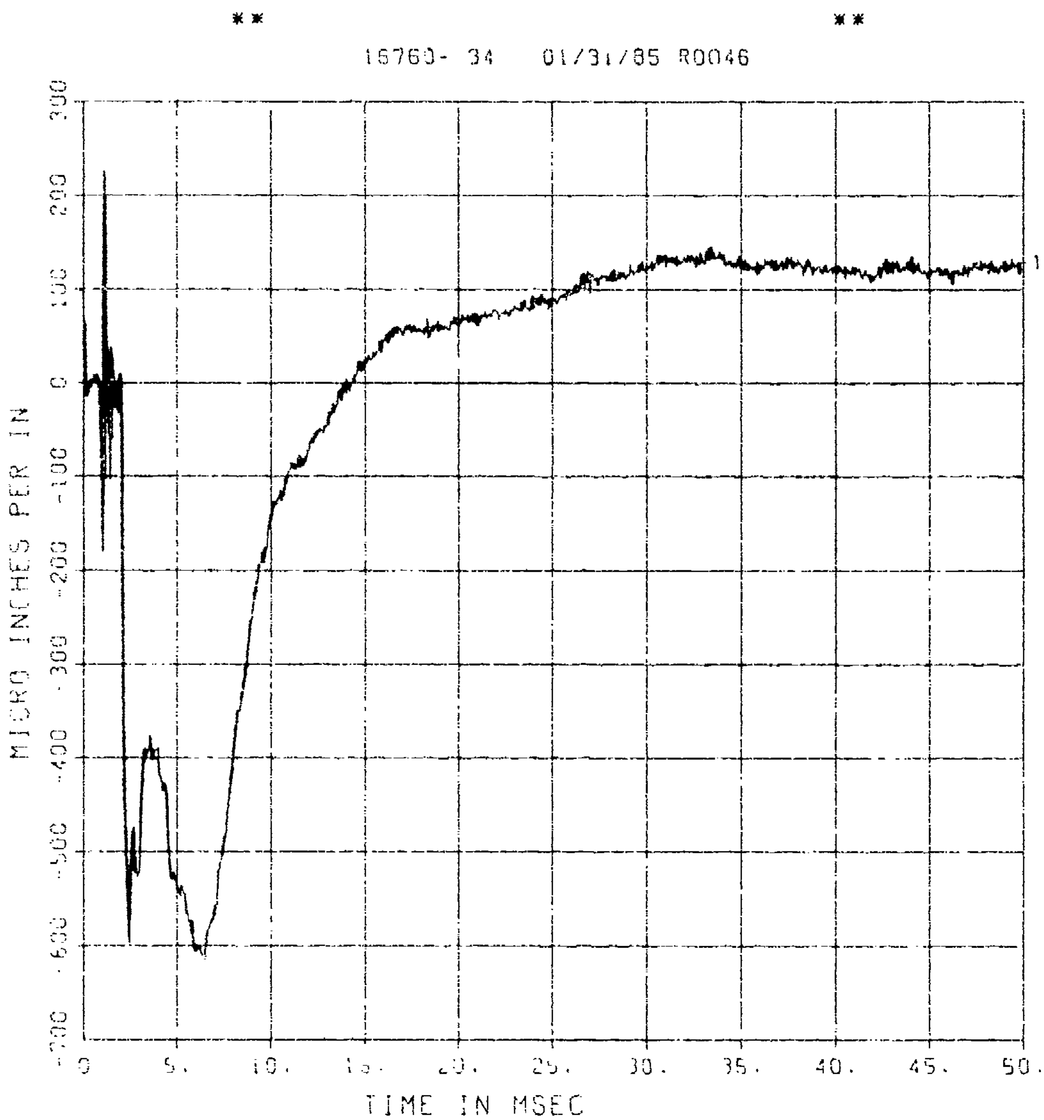


FEMA YIELD EFFECTS 4

EI-4

200000. HZ CAL= 2028.

LP2/0 70% CUTOFF= 18000. HZ

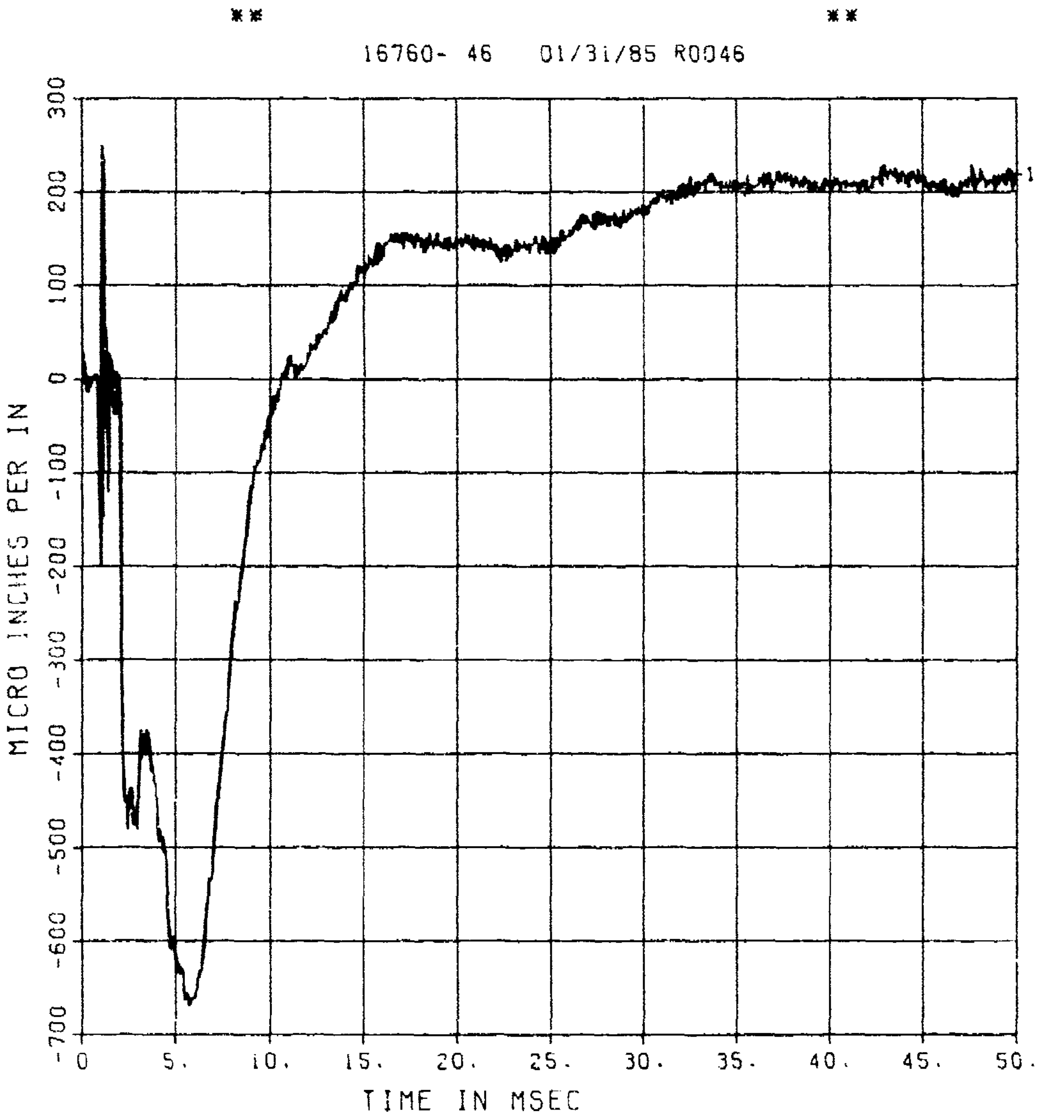


FEMA YIELD EFFECTS 4

EI-4A

200000. HZ CAL= 2028.

LP2/0 70% CUTOFF= 18000. HZ

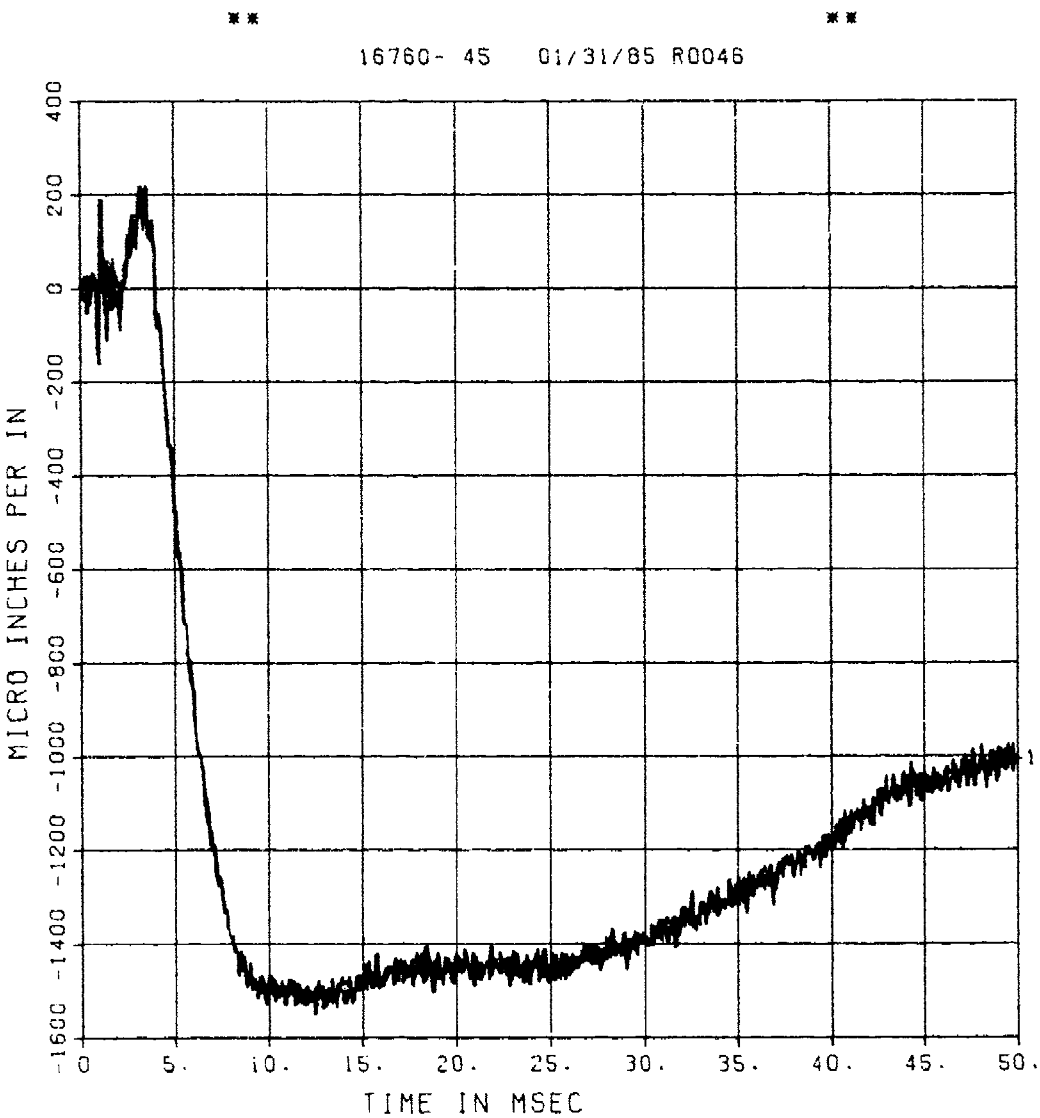


FEMA YIELD EFFECTS 4

EO-4A

200000. HZ CAL= 10004.

LP2/0 70% CUTOFF= 18000. HZ

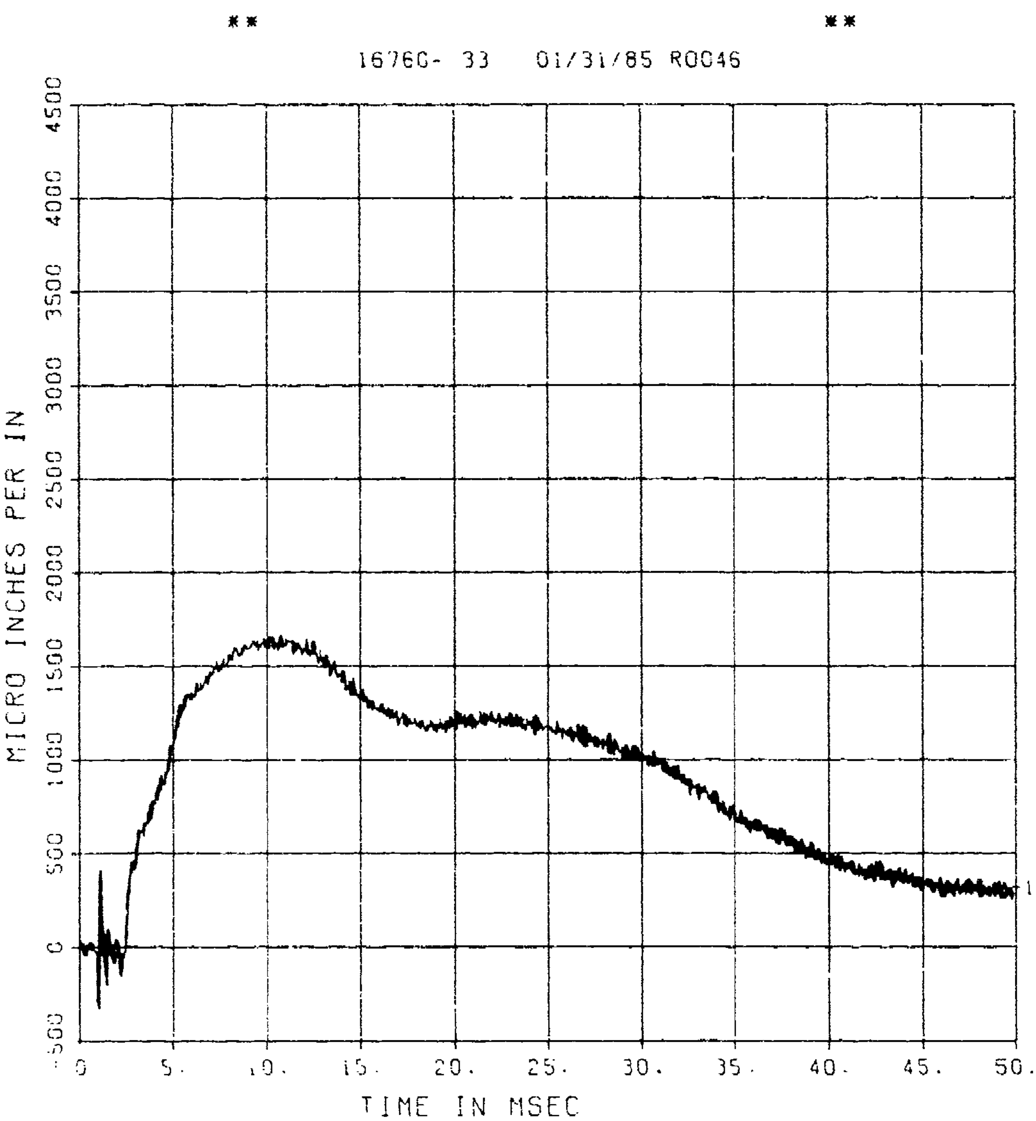


FEMA YIELD EFFECTS 4

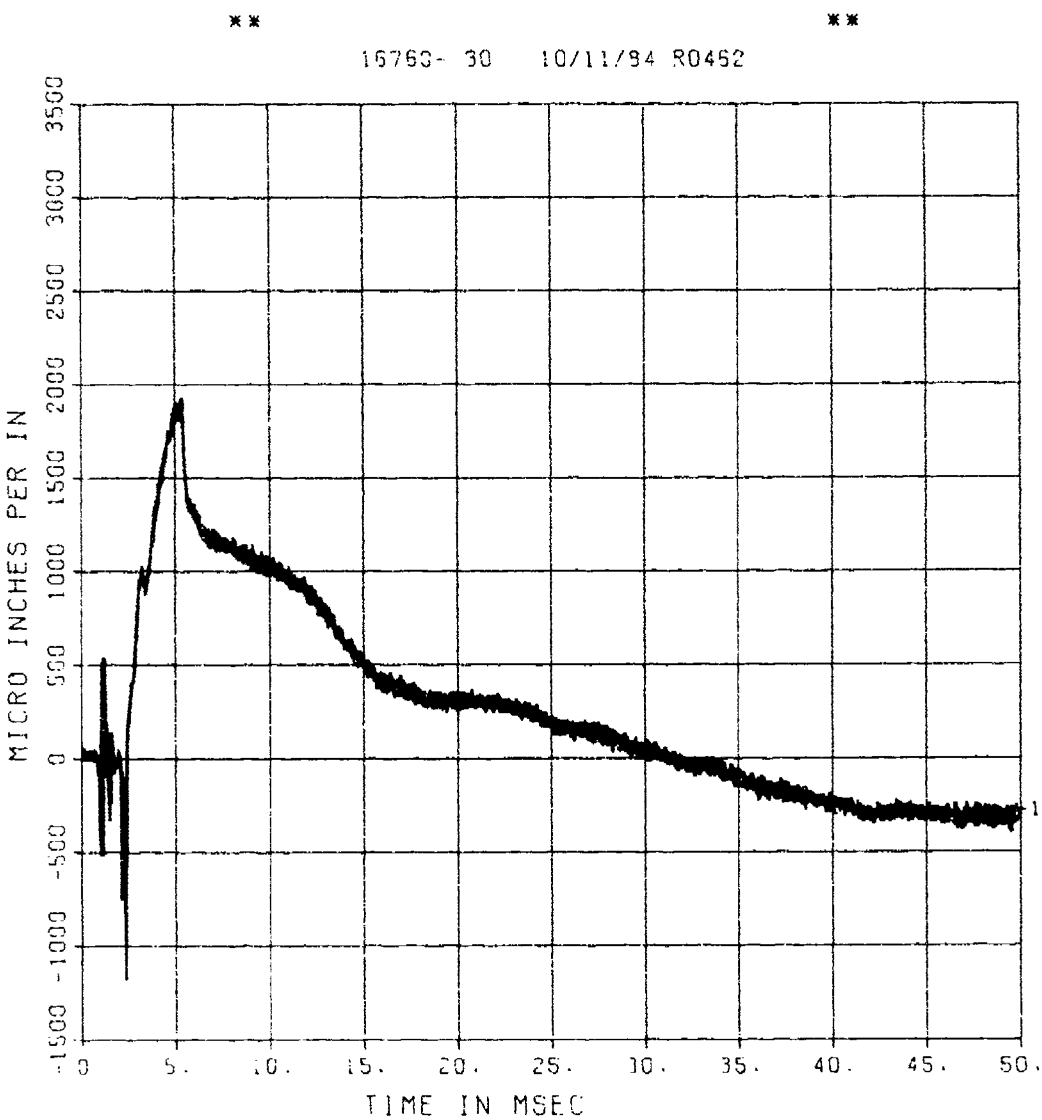
EO-4

200000. HZ CAL= 10004.

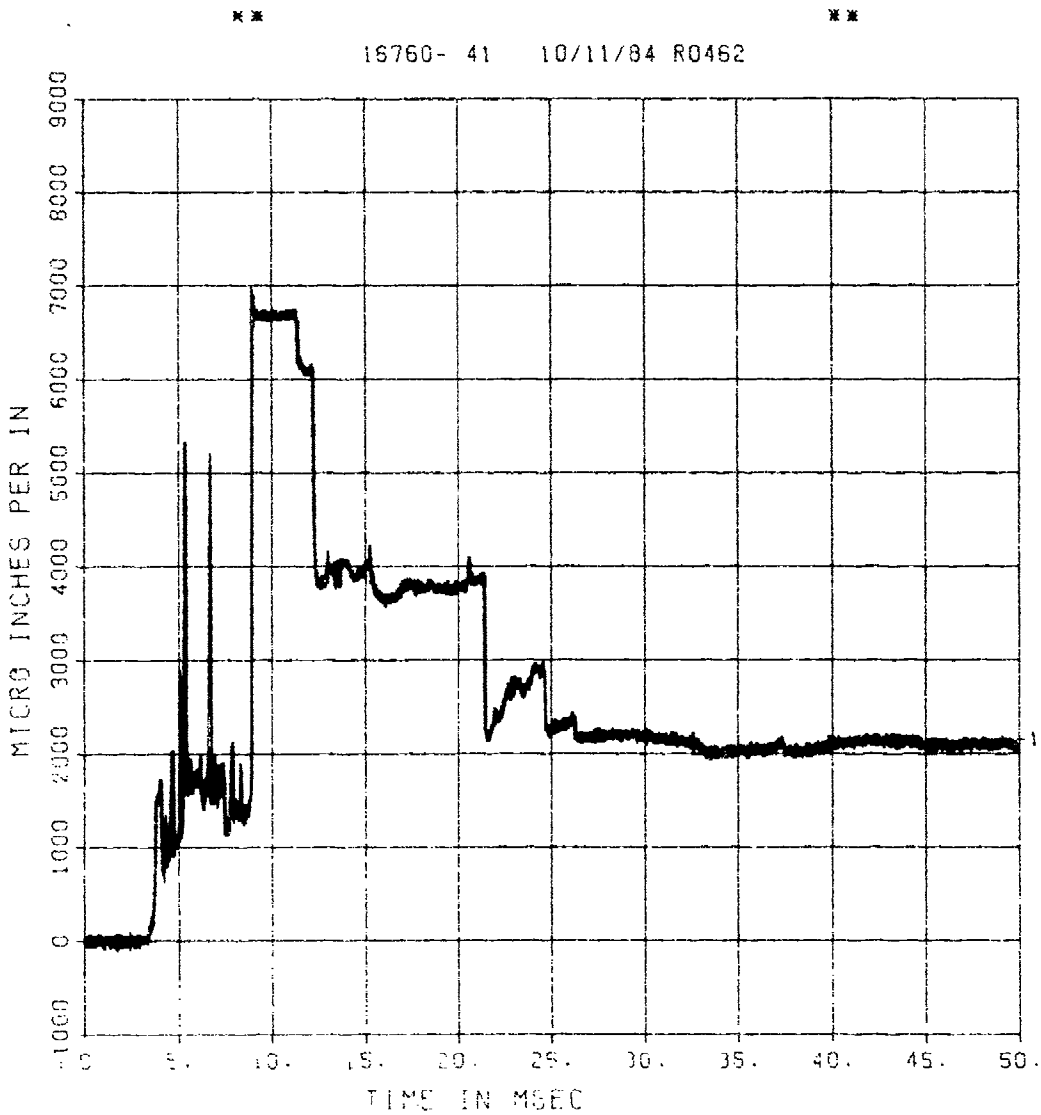
LP2/0 70% CUTOFF= 18000. HZ



FEMA YIELD EFFECTS 4
E-5
200000. HZ CAL= 6686.



FEMA YIELD EFFECTS 4
E-5A
200000. HZ CAL= 6686.

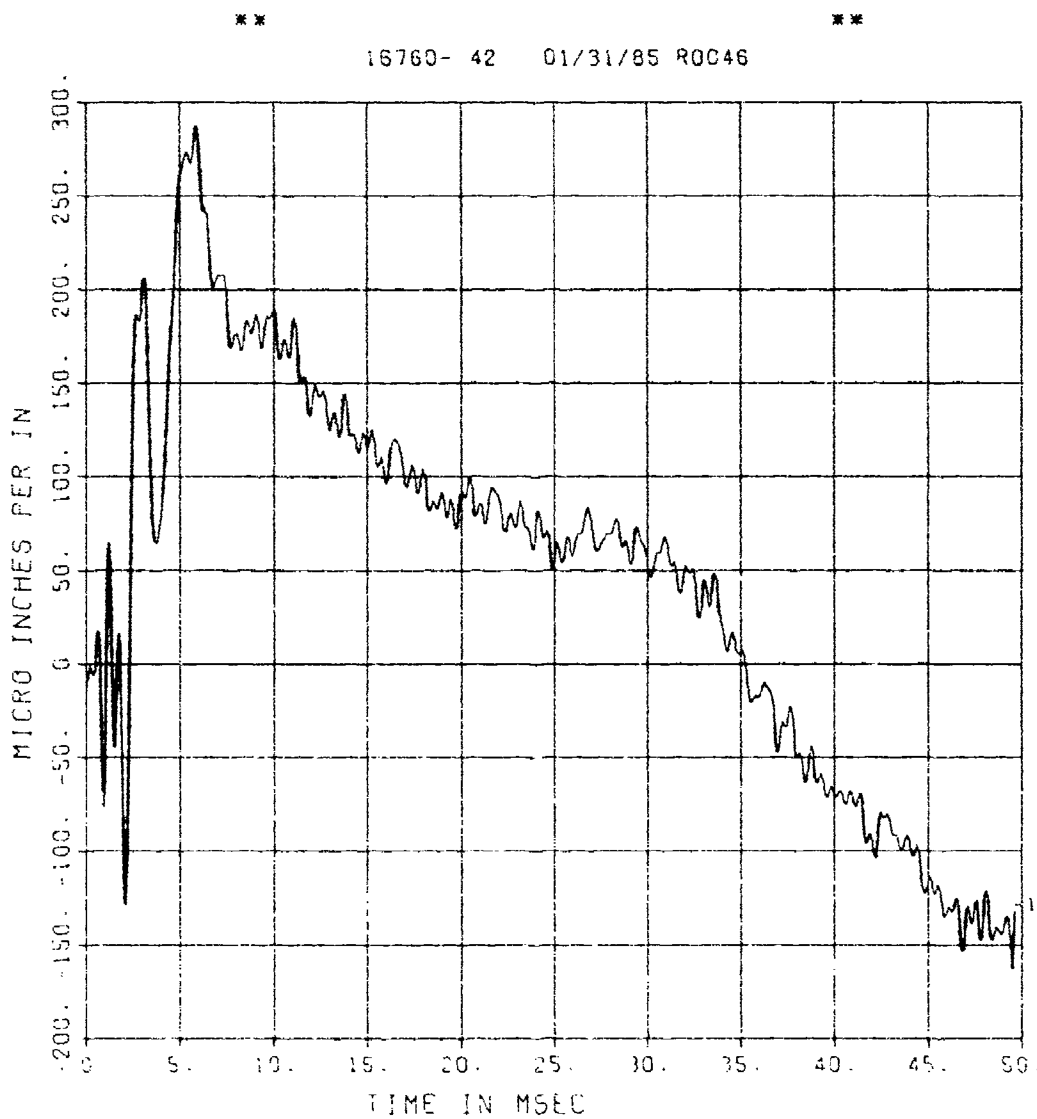


FEMA YIELD EFFECTS 4

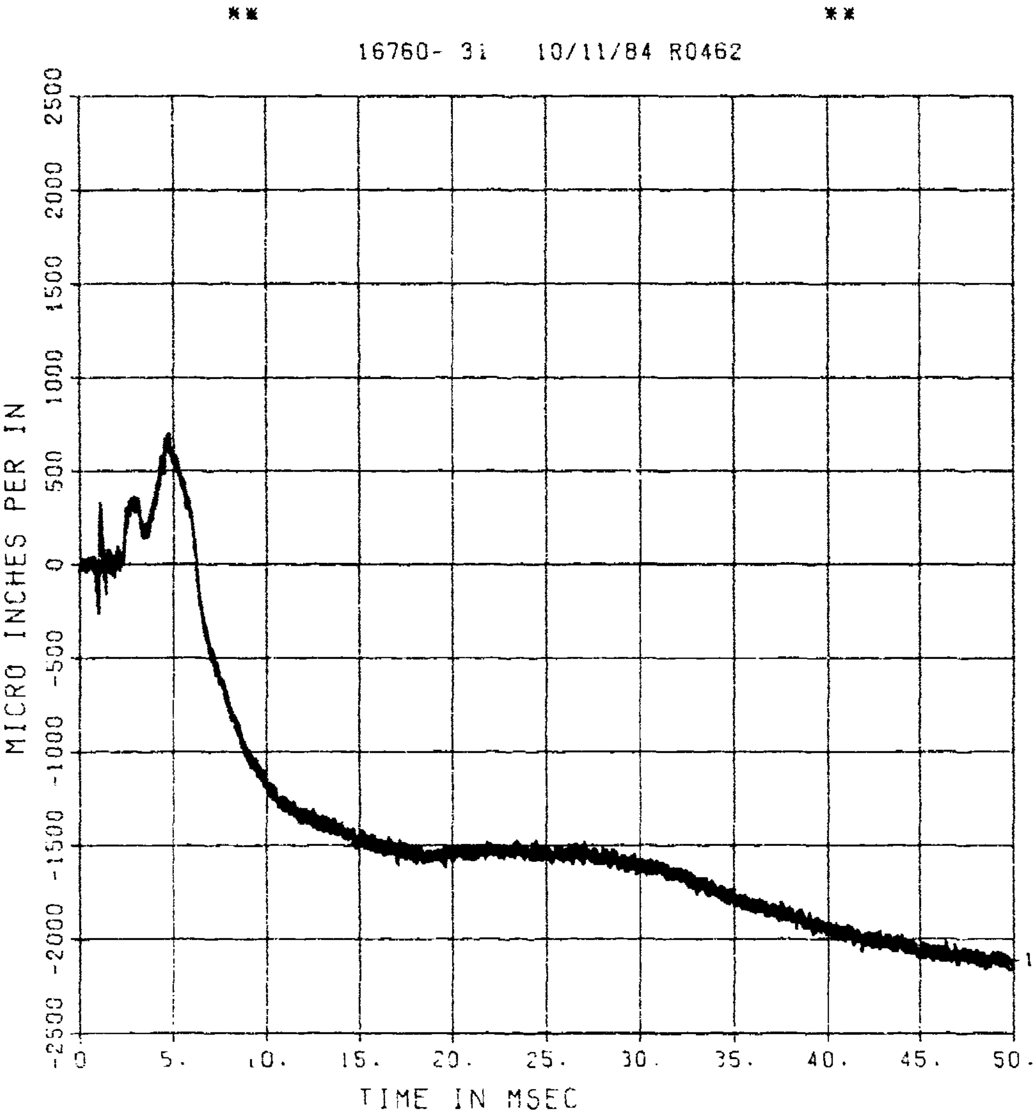
E-6A

50000. HZ CAL= 10004.

LP4/4 70% CUTOFF= 2250. HZ



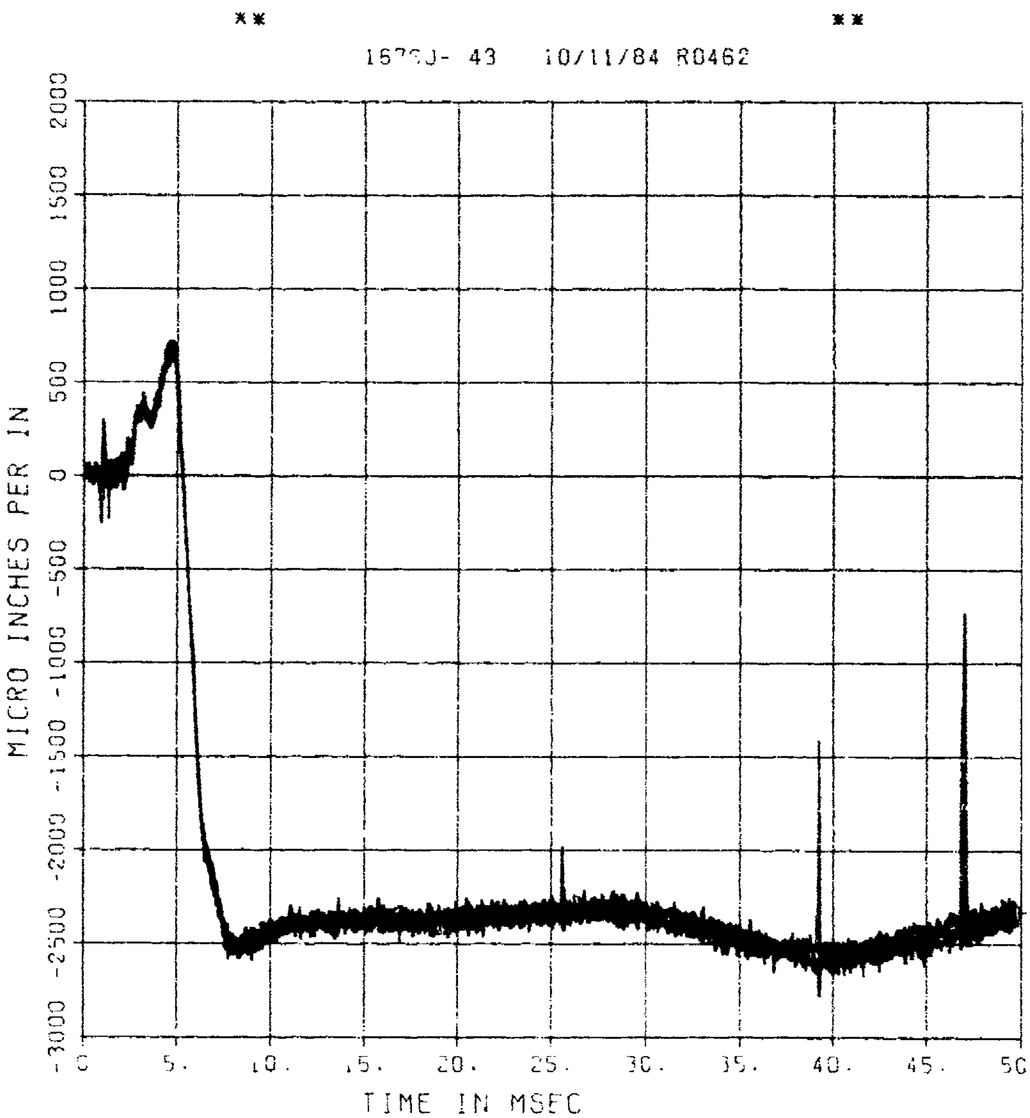
FEMA YIELD EFFECTS 4
E-7
200000. HZ CAL= 6686.



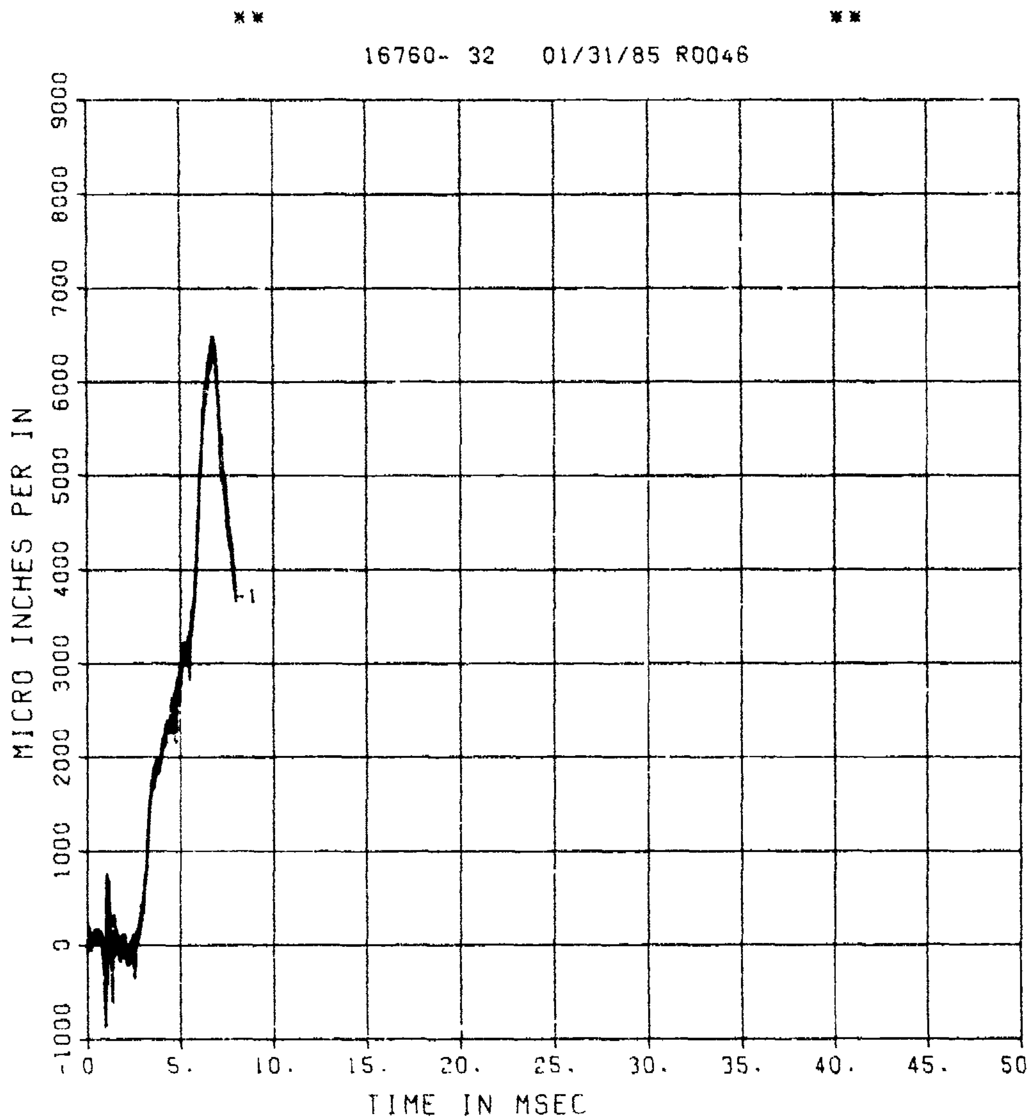
FEMA YIELD EFFECTS 4

E-7A

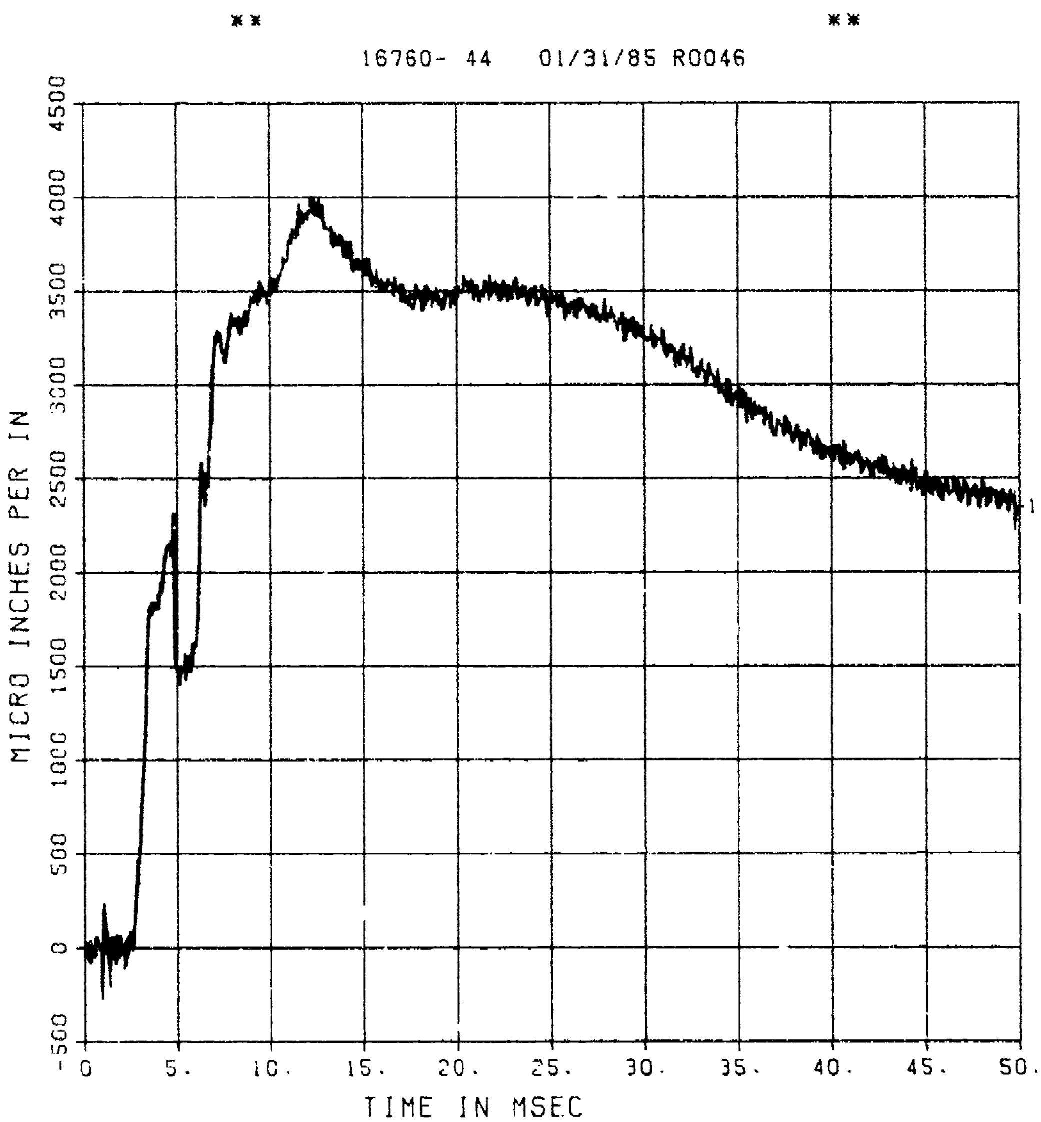
200000. HZ CAL= 6686.



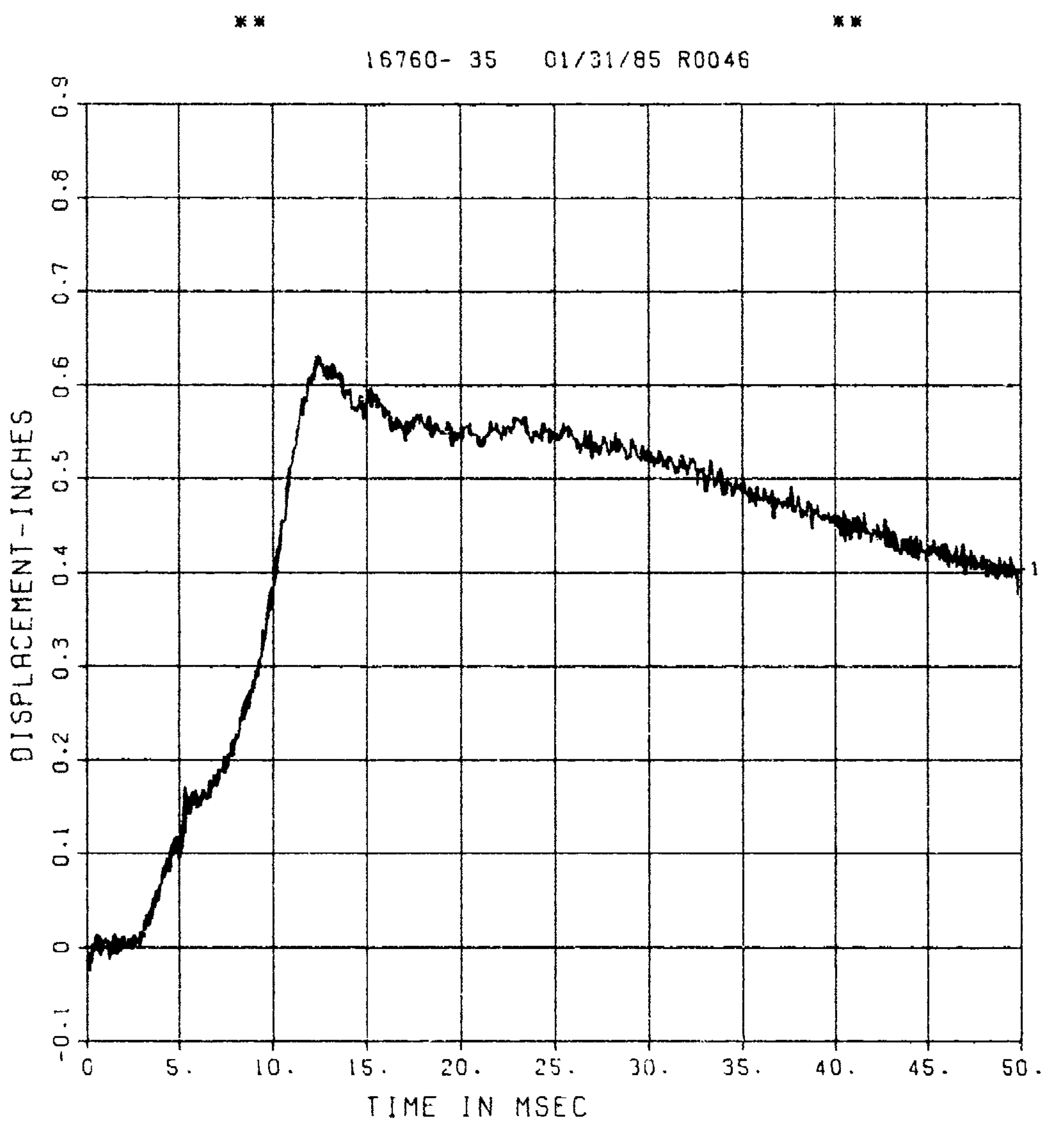
FEMA YIELD EFFECTS 4
E-8
200000. HZ CAL= 19670.



FEMA YIELD EFFECTS 4
E-8A
200000. HZ CAL= 19670.
LP2/0 70% CUTOFF= 18000. HZ



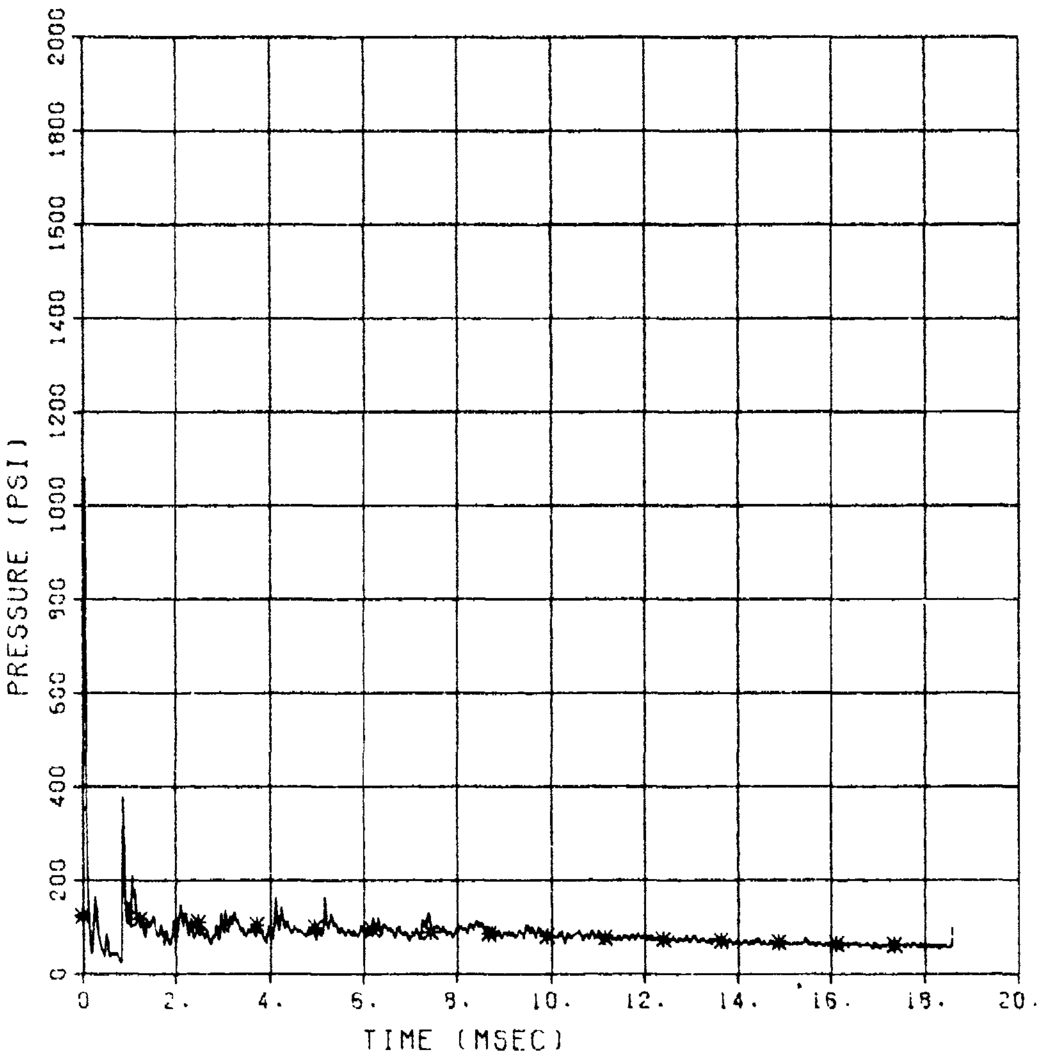
FEMA YIELD EFFECTS 4
D-1
200000. HZ CAL= 3.080
LP2/0 70% CUTOFF= 18000. HZ



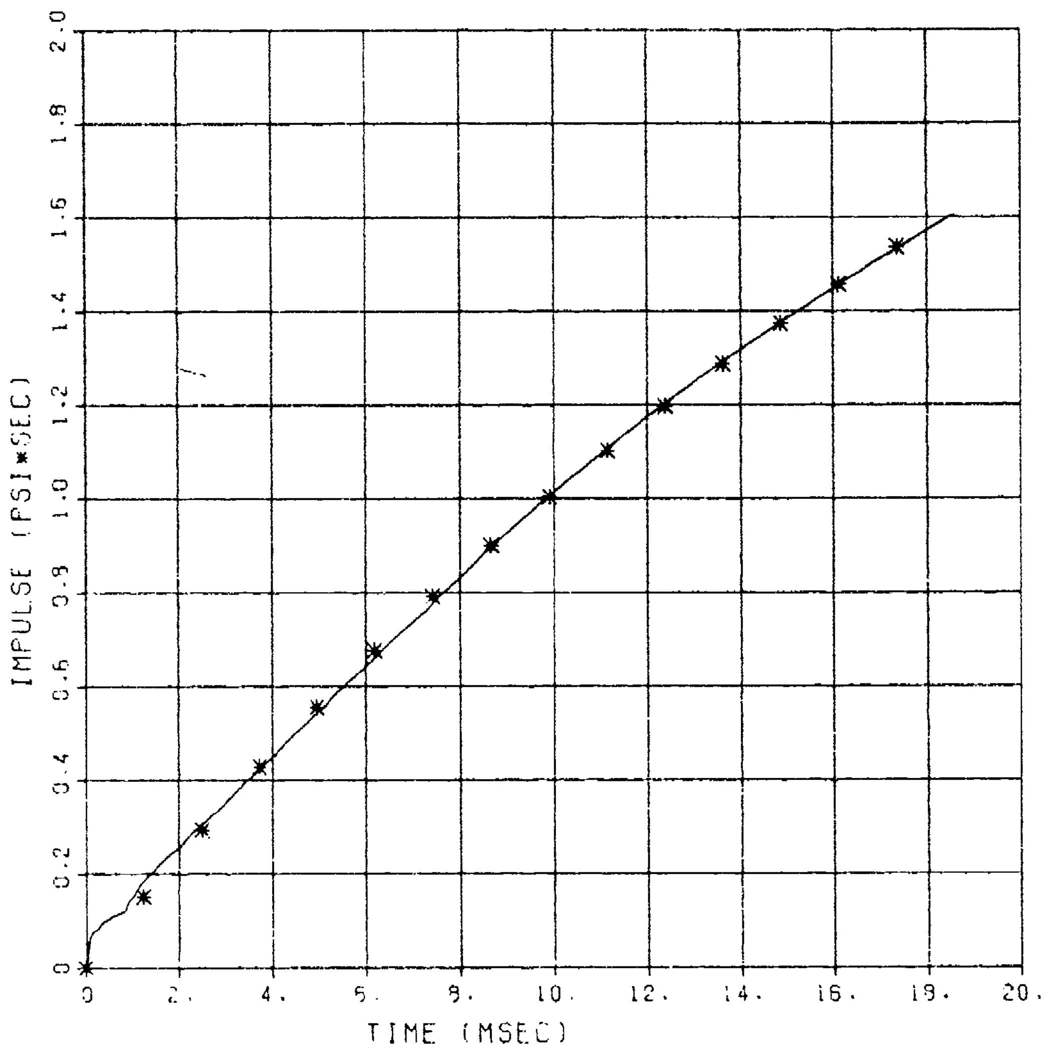
APPENDIX B

WEAPON FITS

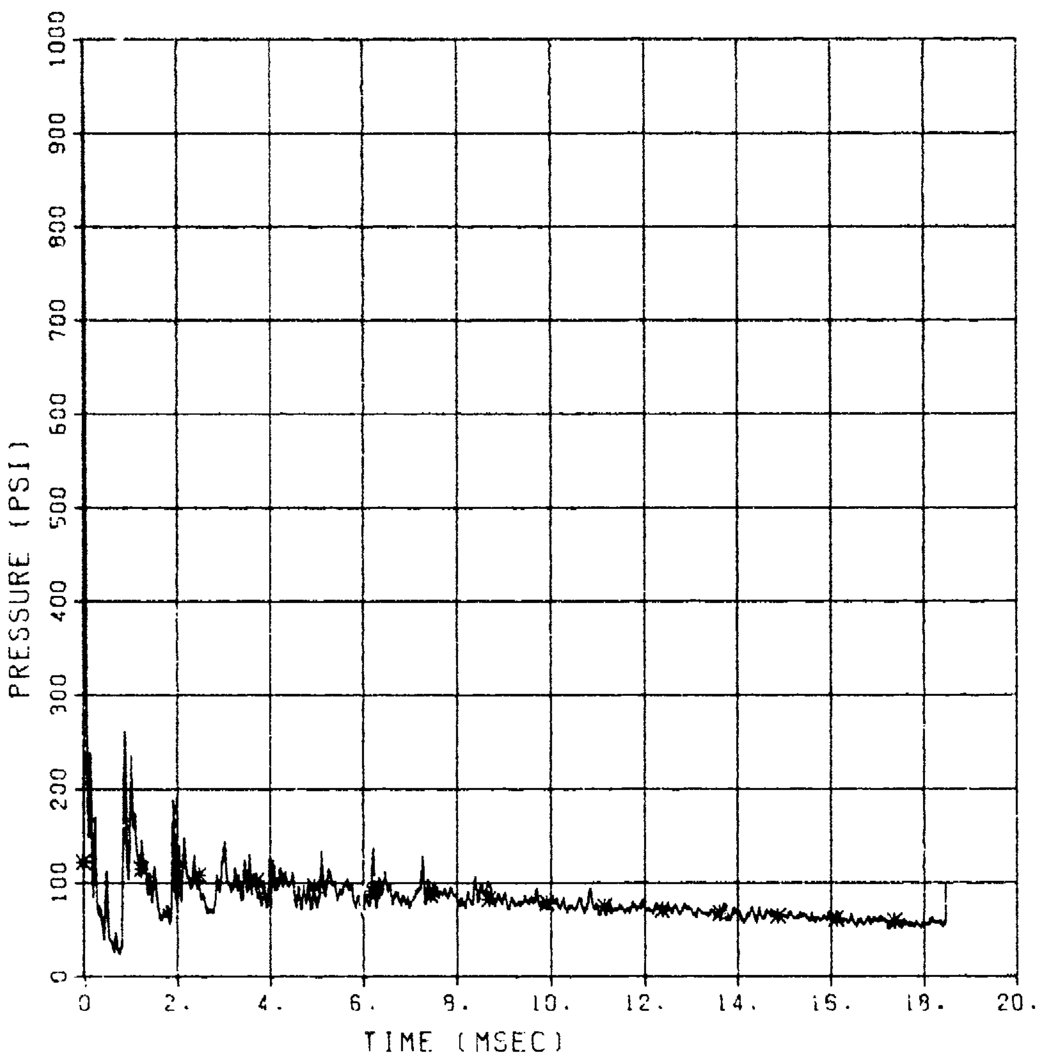
PRESSURE COMPARISON
FEMA YIELD EFFECTS 1
BP-1
SPEICHER-BRODE
W(KT) = 11.893
P(PSI) =125.
HOBF(KFT) = 0.
09/07/84 1578E



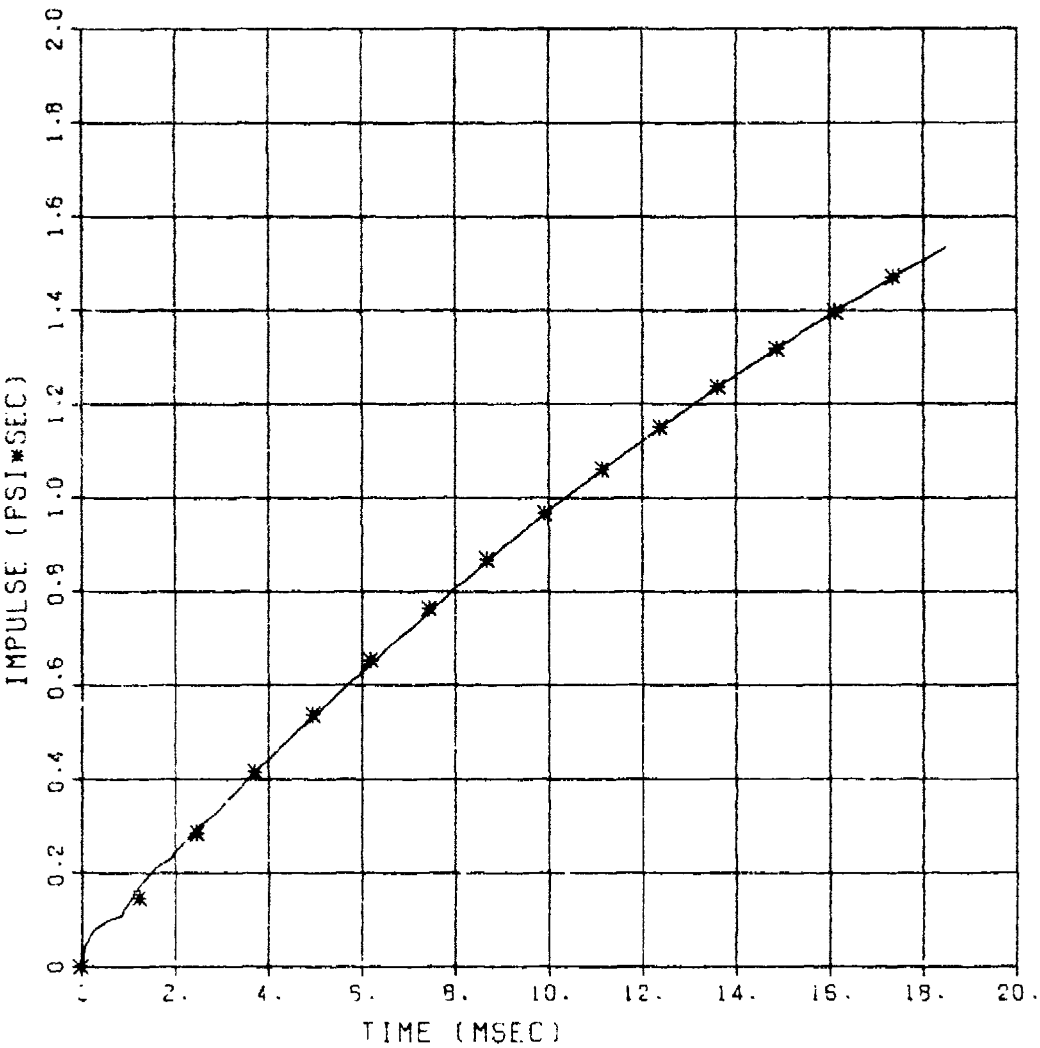
IMPULSE COMPARISON
FEMA YIELD EFFECTS 1
BP-1
SPEICHER-BRODE
W(KT) = 11.893
P(PSI) =125.
HOBF(KFT) = 0.
09/07/84 1578E



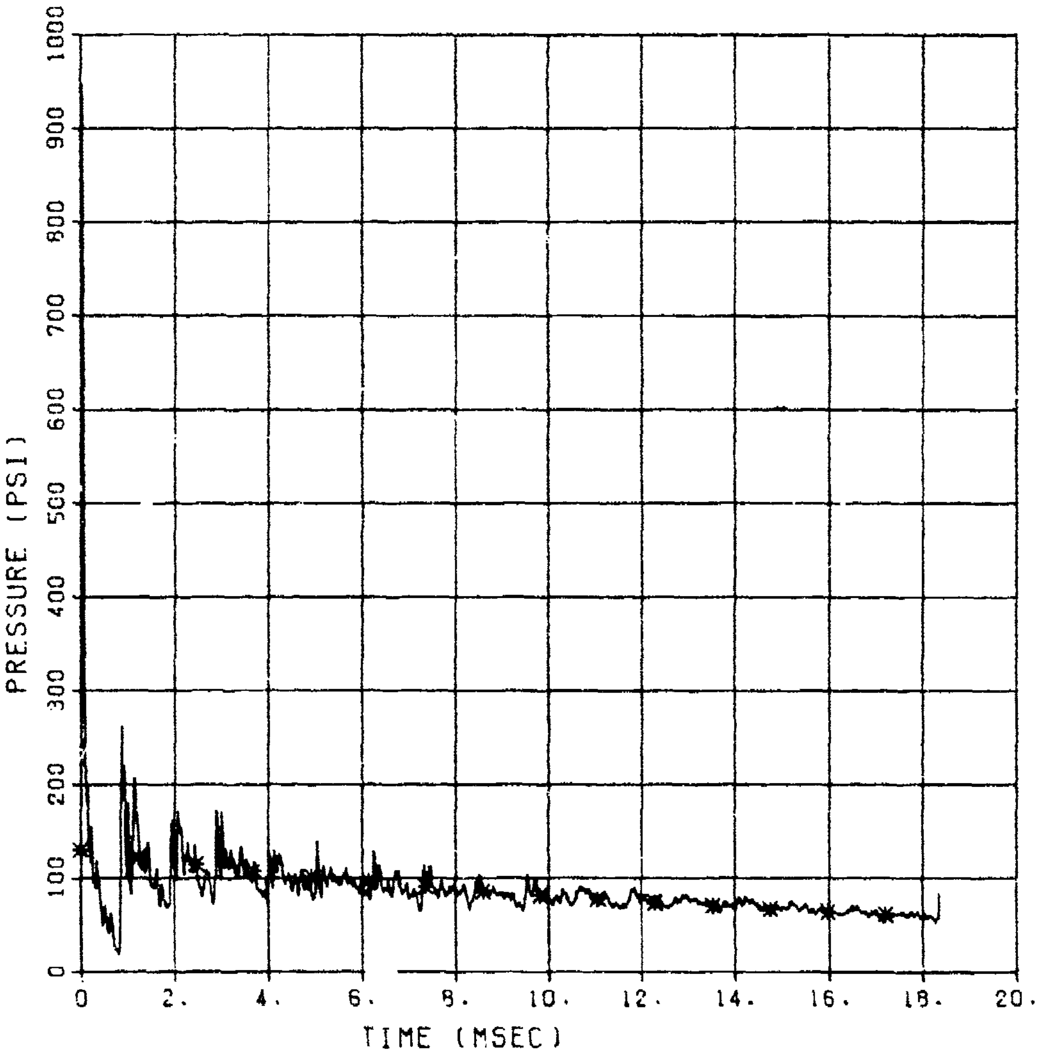
PRESSURE COMPARISON
FEMA YIELD EFFECTS 1
BP-2
SPEICHER-BRODE
W(KT) = 9.195
P(PSI) =122.
HOBF(KFT) = 0.
09/07/84 1578E



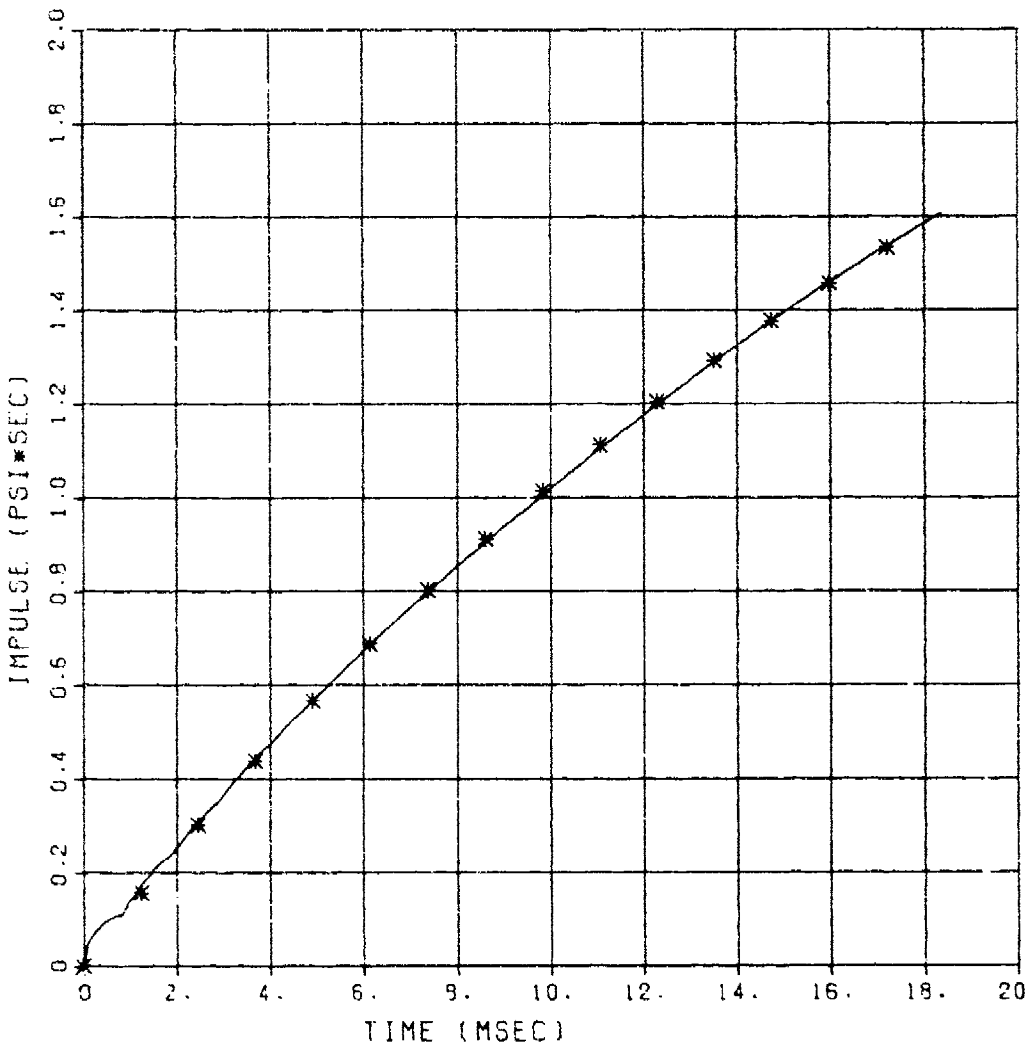
IMPULSE COMPARISON
FEMA YIELD EFFECTS 1
BP-2
SPEICHER-BRODE
W(KT) = 9.195
P(PSI) =122.
HOBF(KFT) = 0.
09/07/84 1578E



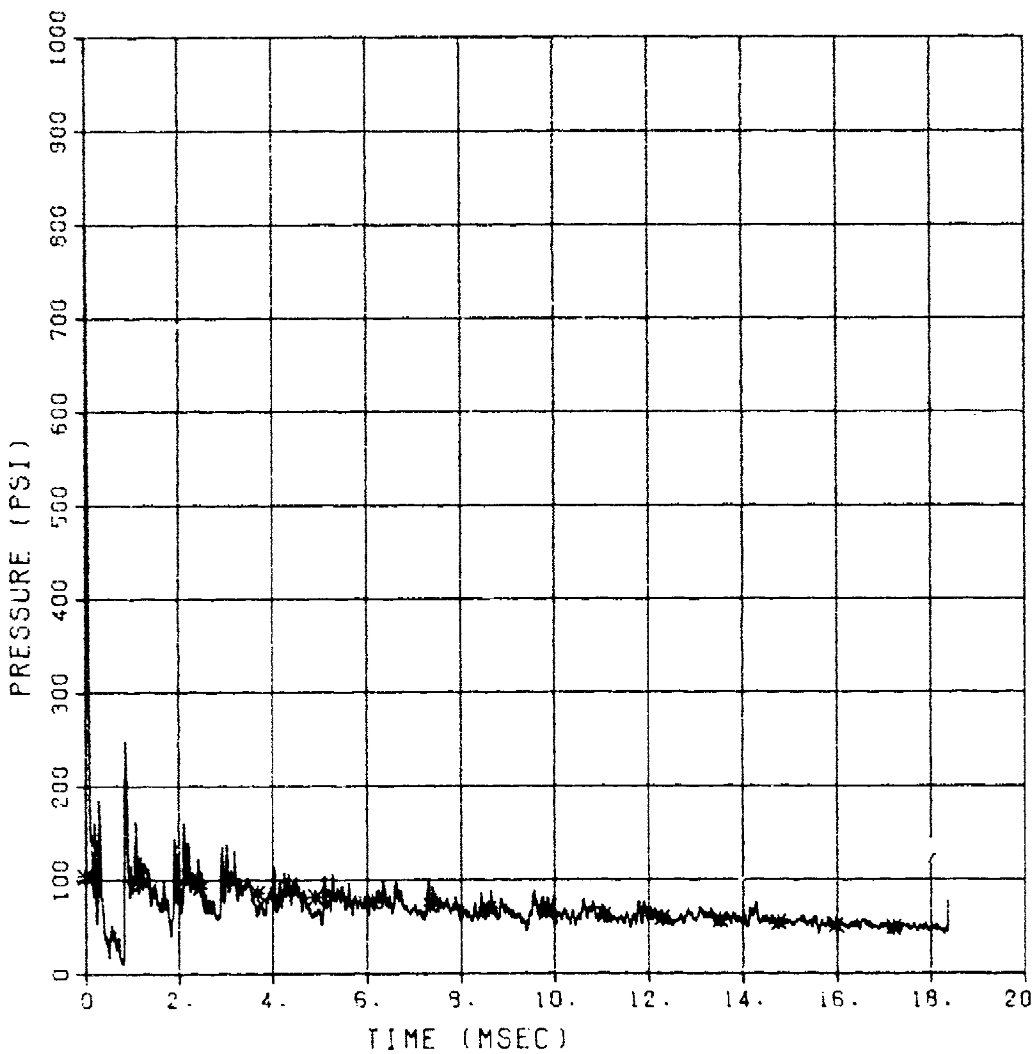
PRESSURE COMPARISON
FEMA YIELD EFFECTS 1
BP-3
SPEICHER-BRODE
W(KT) = 9.520
P(PSI) =130.
HOBF(KFT) = 0.
09/07/84 1578E



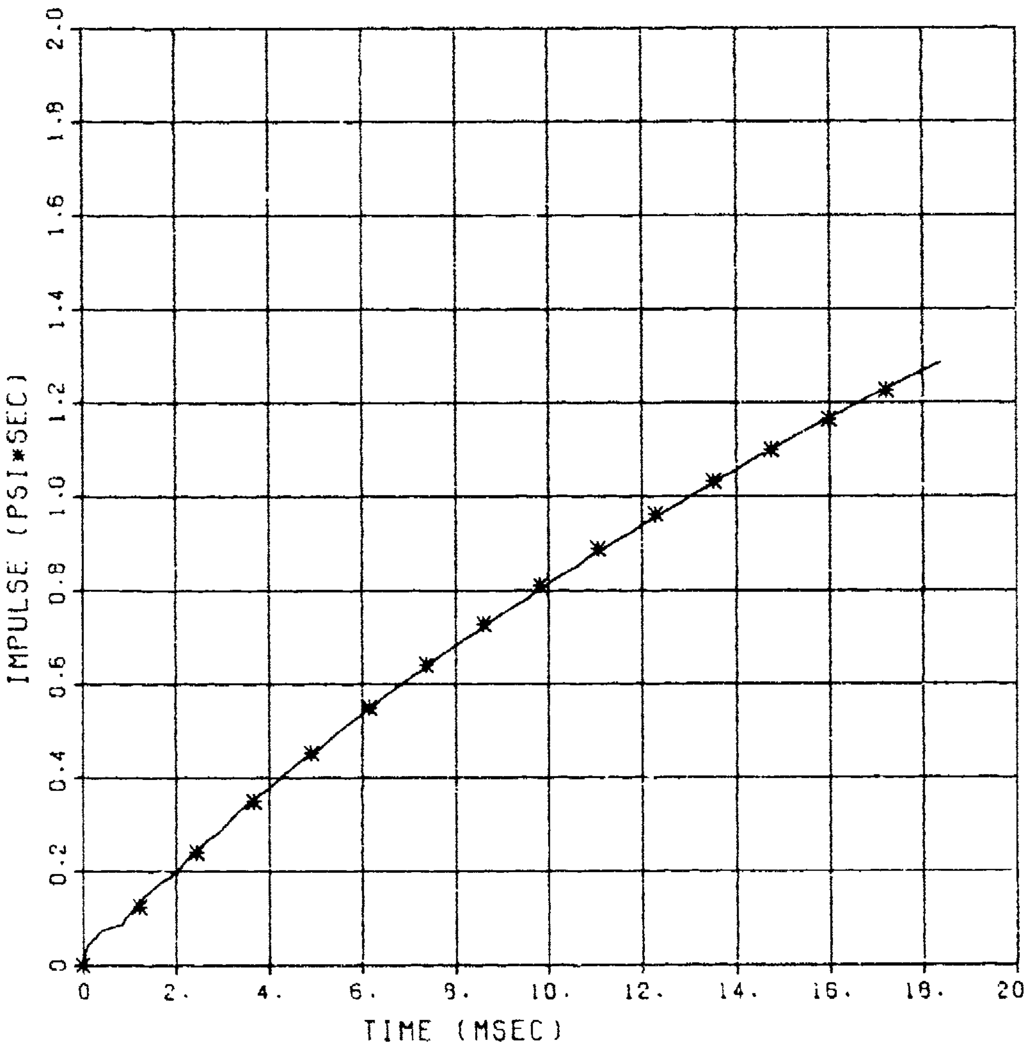
IMPULSE COMPARISON
FEMA YIELD EFFECTS 1
BP-3
SPEICHER-BRODE
W(KT) = 9.520
P(PSI) =130.
HOBF(KFT) = 0.
09/07/84 1578E



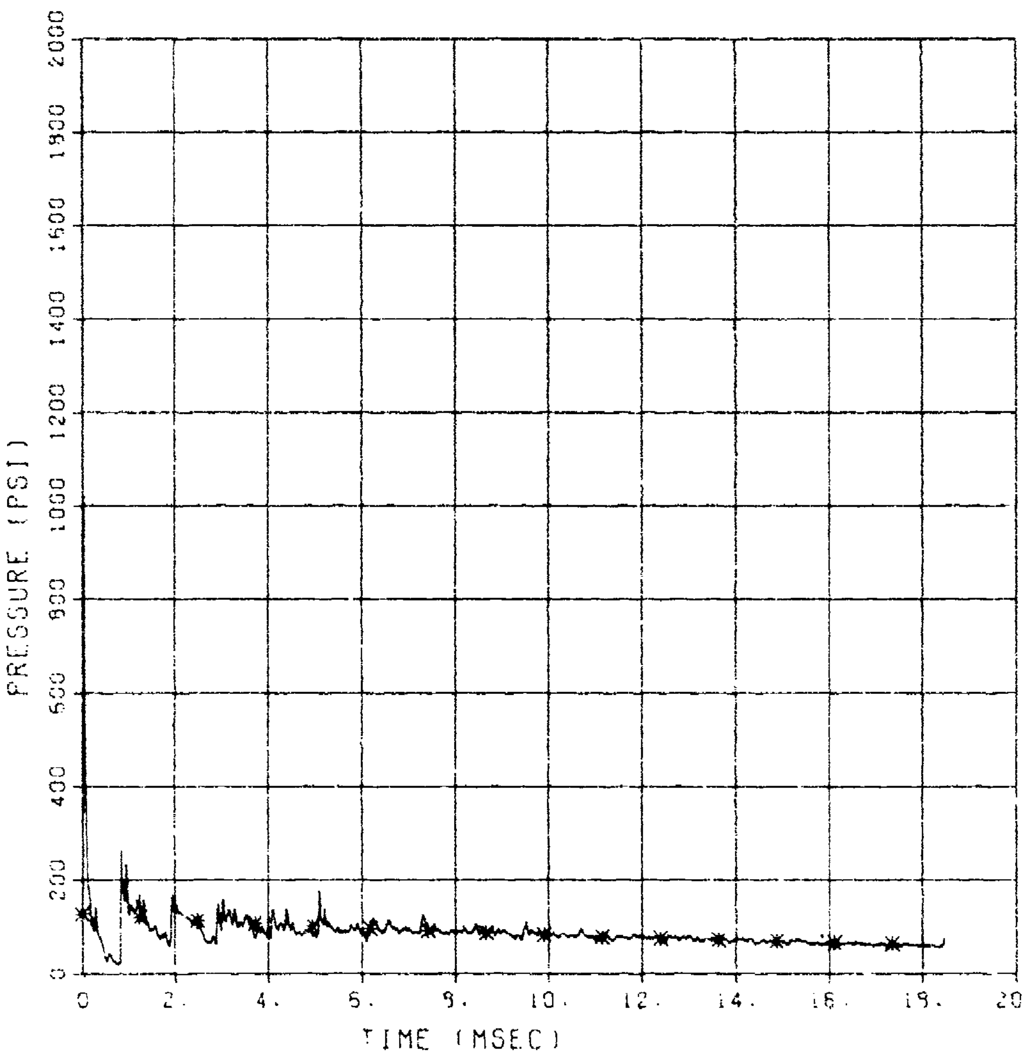
PRESSURE COMPARISON
FEMA YIELD EFFECTS 1
BP-4
SPEICHER-BRODE
W(KT) = 4.340
P(PSI) =104.
HOBF(KFT) = 0.
09/07/84 1578E



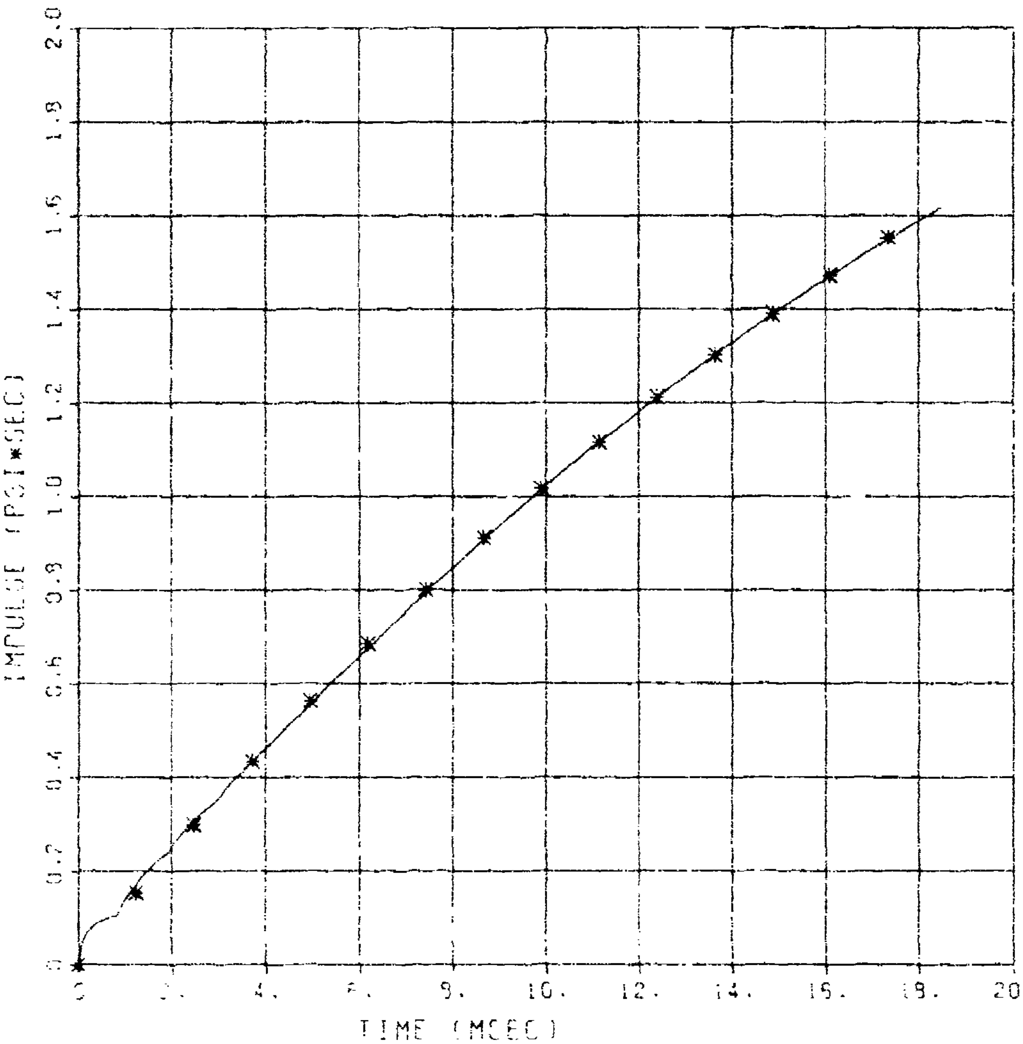
IMPULSE COMPARISON
FEMA YIELD EFFECTS 1
BP-4
SPEICHER-BRODE
W(KT) = 4.340
P(PSI) =104.
HOBF(KFT) = 0.
09/07/84 1578E



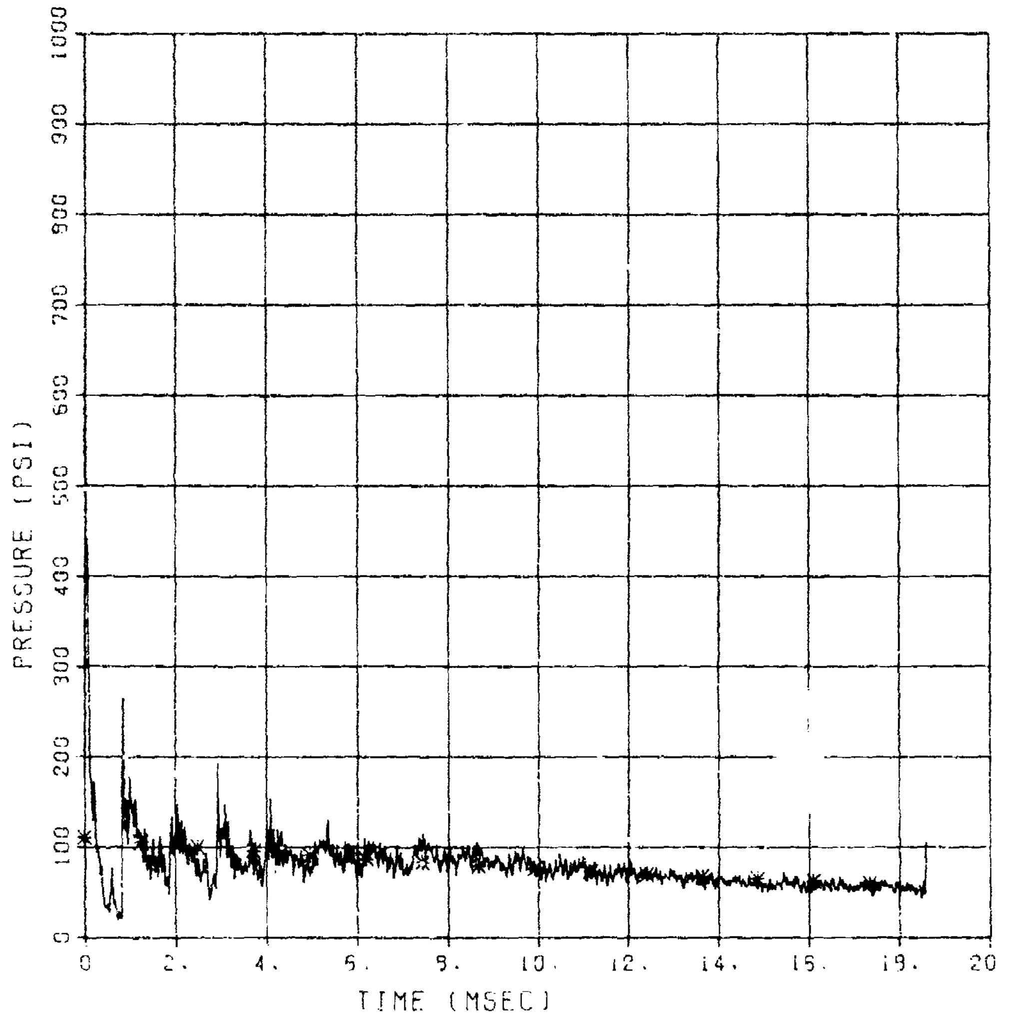
PRESSURE COMPARISON
FEMA YIELD EFFECTS 1
BP-5
SPEICHER-BRODE
W(KT) = 11.950
P(PSI) =127.
HOBF(KFT) = 0.
09/07/84 1578E



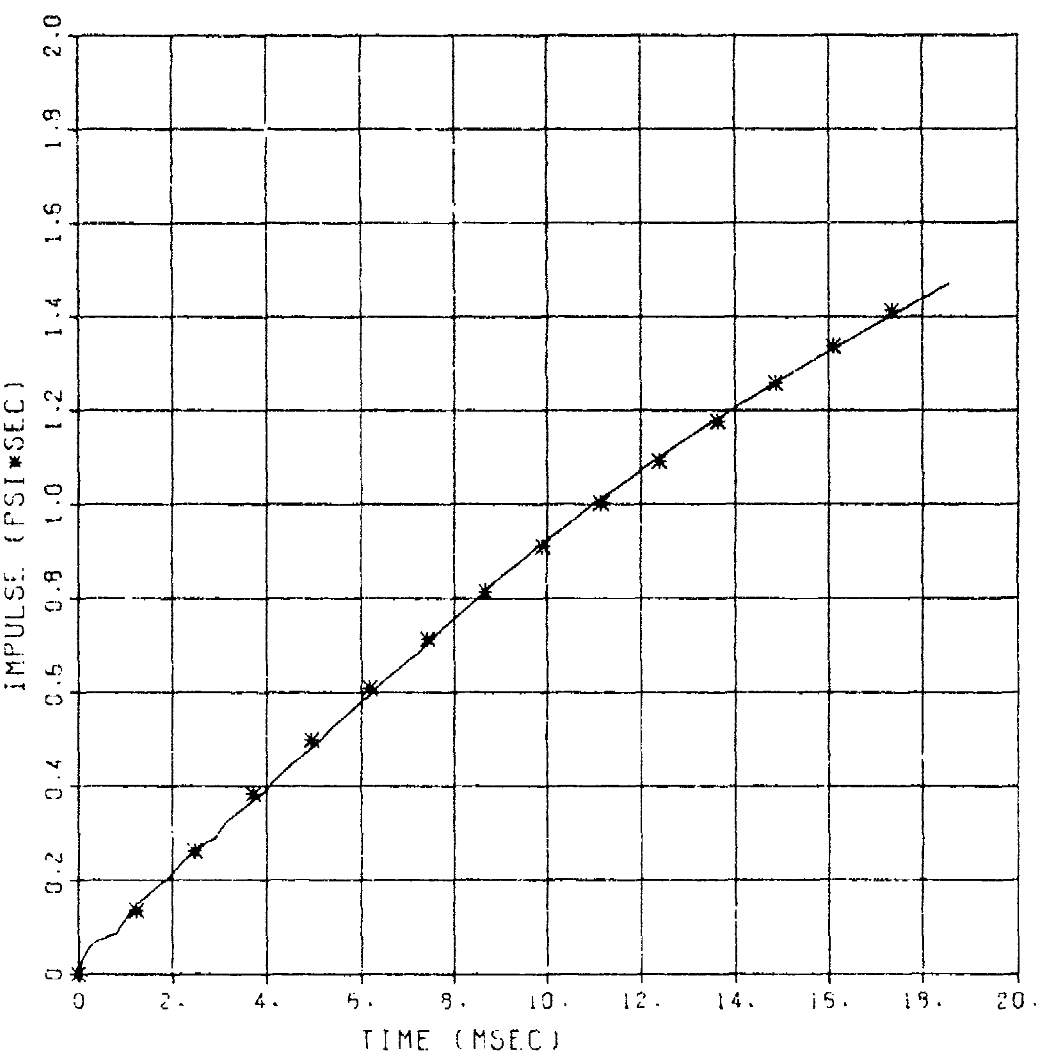
IMPULSE COMPARISON
FEMA YIELD EFFECTS 1
BP-5
SPEICHER-BRODE
W(KT) = 11.950
P(PSI) =127.
HOBF(KFT) = 0.
09/07/84 1578E



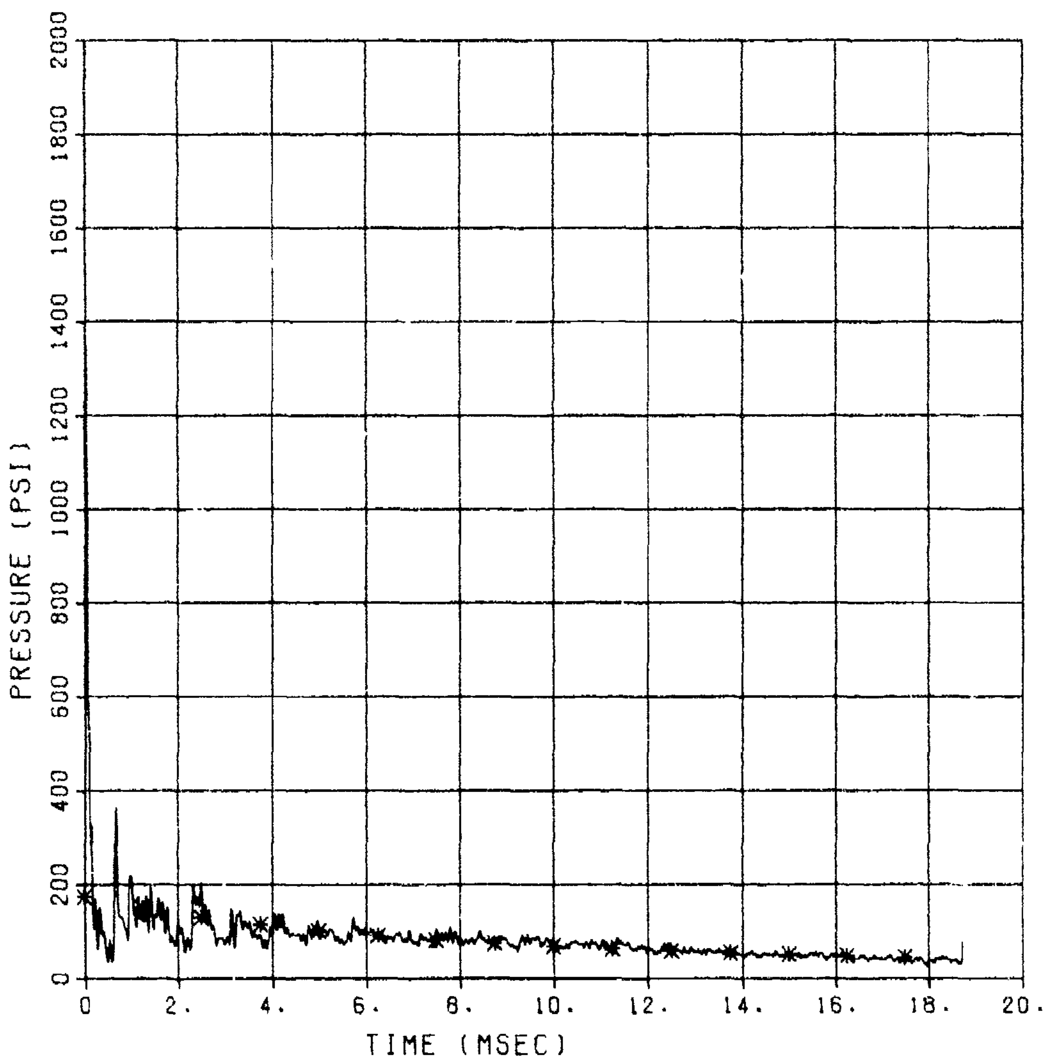
PRESSURE COMPARISON
FEMA YIELD EFFECTS 1
BP-6
SPEICHER-BRODE
W(KT) = 11.745
P(PSI) =111.
HOBF(KFT) = 0.
09/07/84 1578E



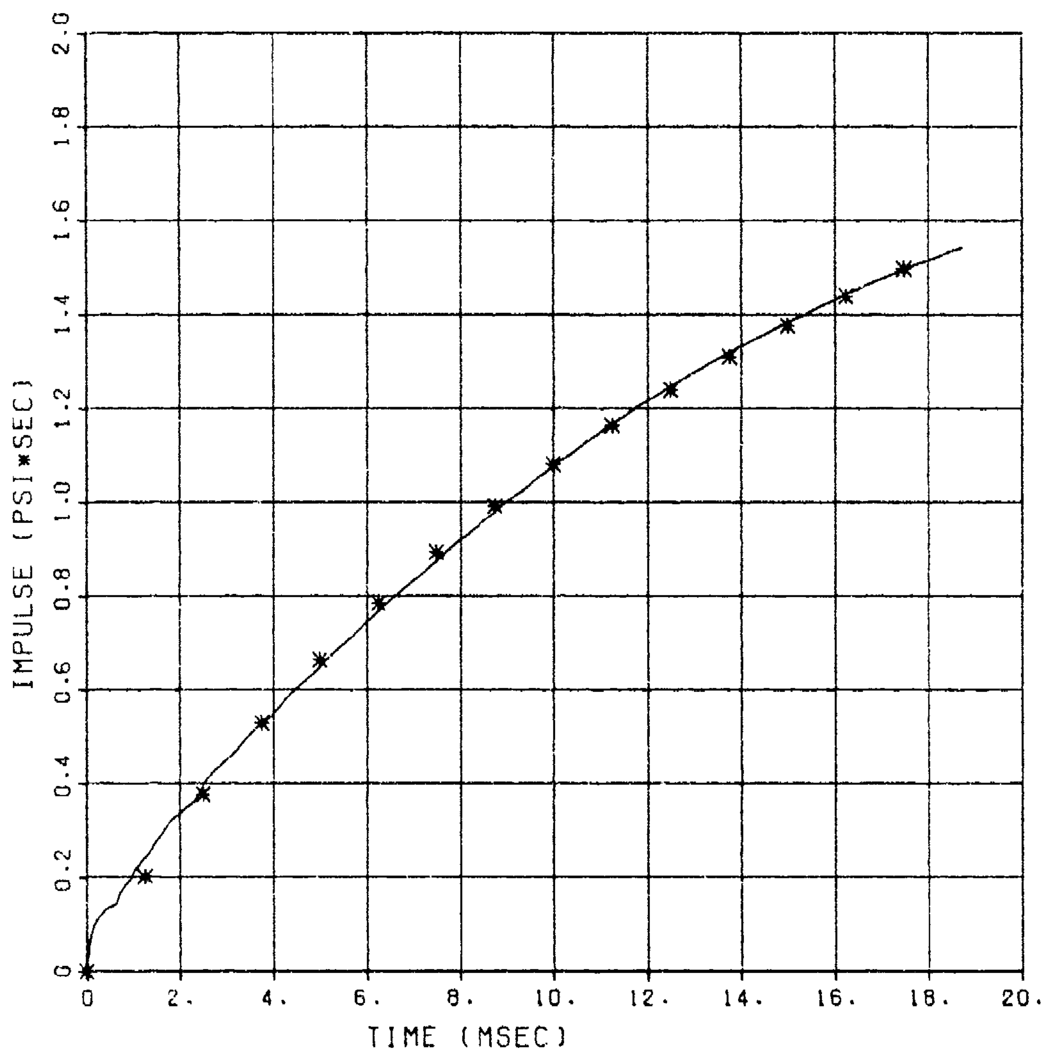
IMPULSE COMPARISON
FEMA YIELD EFFECTS 1
BP-6
SPEICHER-BRODE
W(KT) = 11.745
P(PSI) =111.
HOBF(KFT) = 0.
09/07/84 1578E



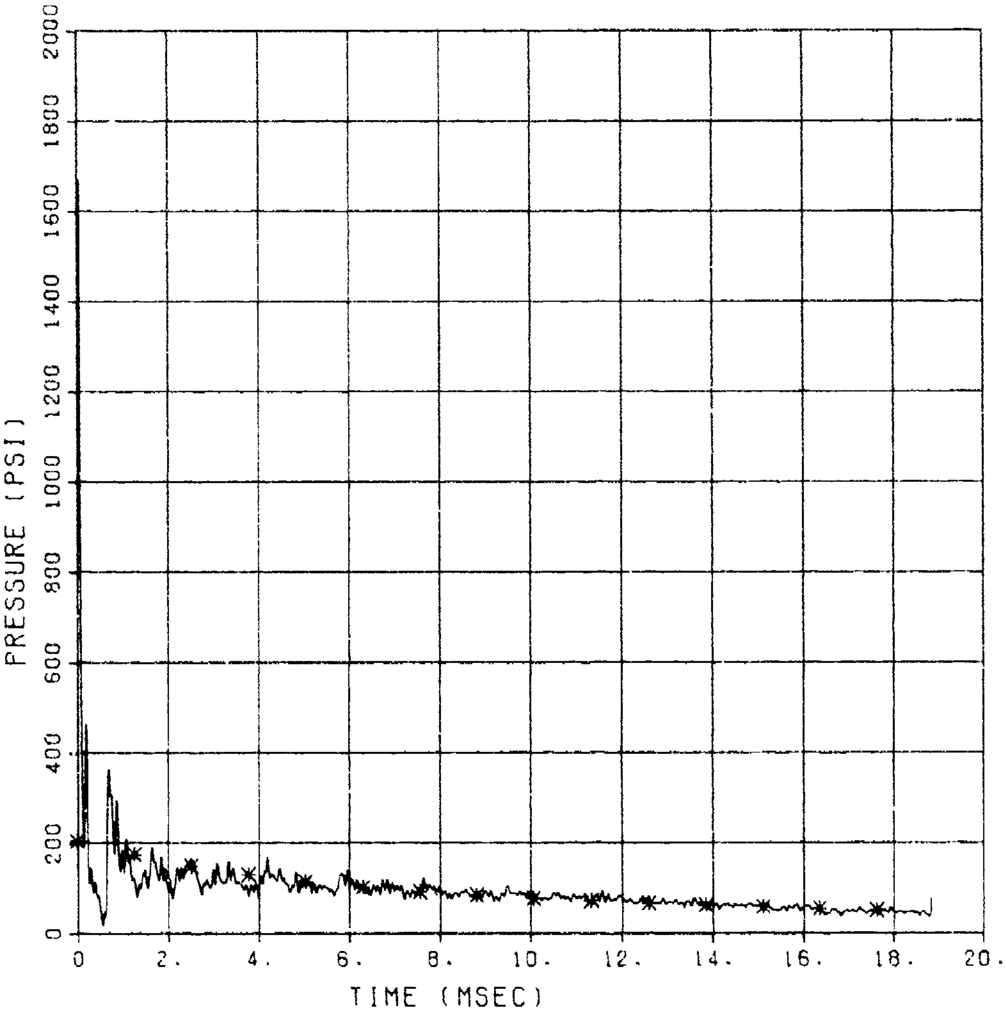
PRESSURE COMPARISON
FEMA YIELD EFFECTS 2
BP-1
SPEICHER-BRODE
W(KT) = 1.597
P(PSI) =174.
HOBF(KFT) = 0.
09/24/84 3544A



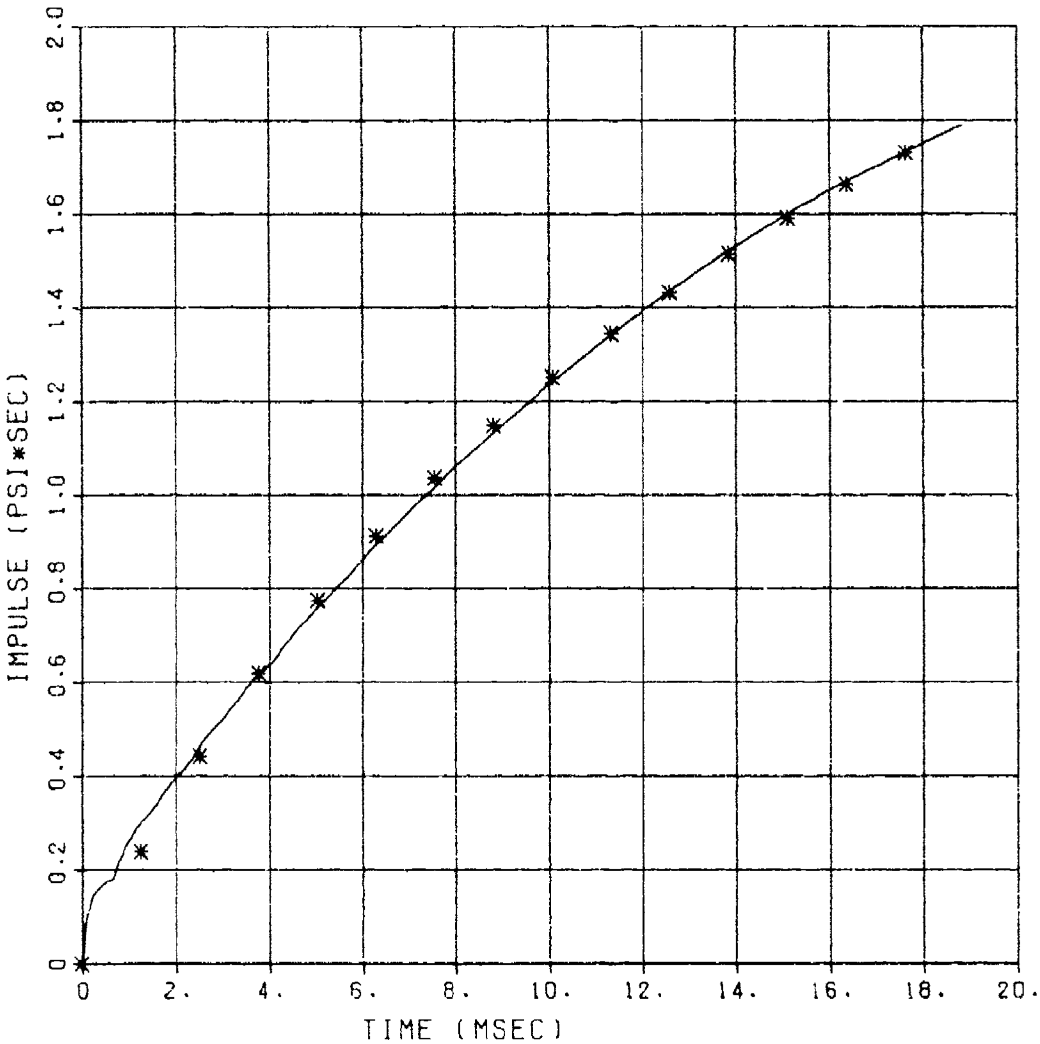
IMPULSE COMPARISON
FEMA YIELD EFFECTS 2
BP-1
SPEICHER-BRODE
W(KT) = 1.597
P(PSI) =174.
HOBF(KFT) = 0.
09/24/84 3544A



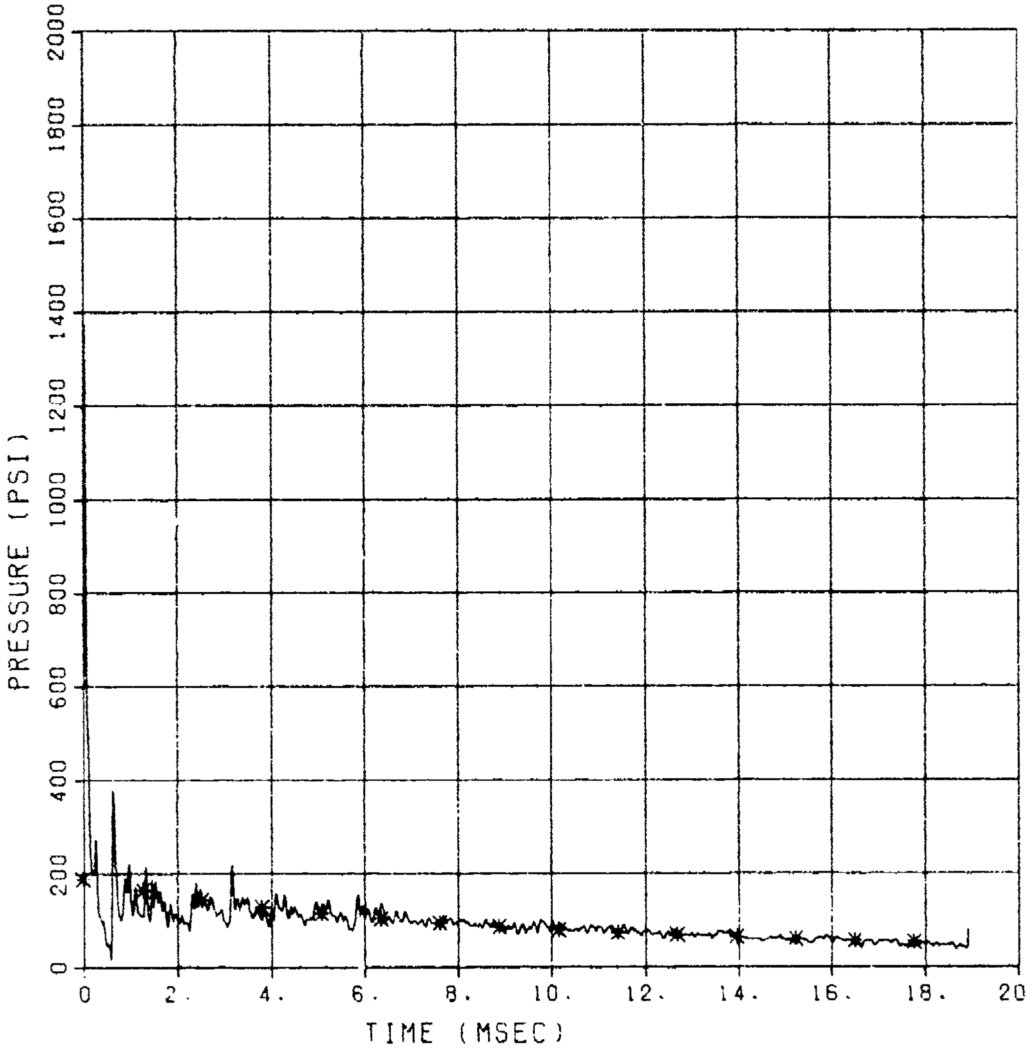
PRESSURE COMPARISON
FEMA YIELD EFFECTS 2
BP-2
SPEICHER-BRODE
W(KT) = 1.838
P(PSI) =206.
HOBF(KFT) = 0.
09/24/84 3544A



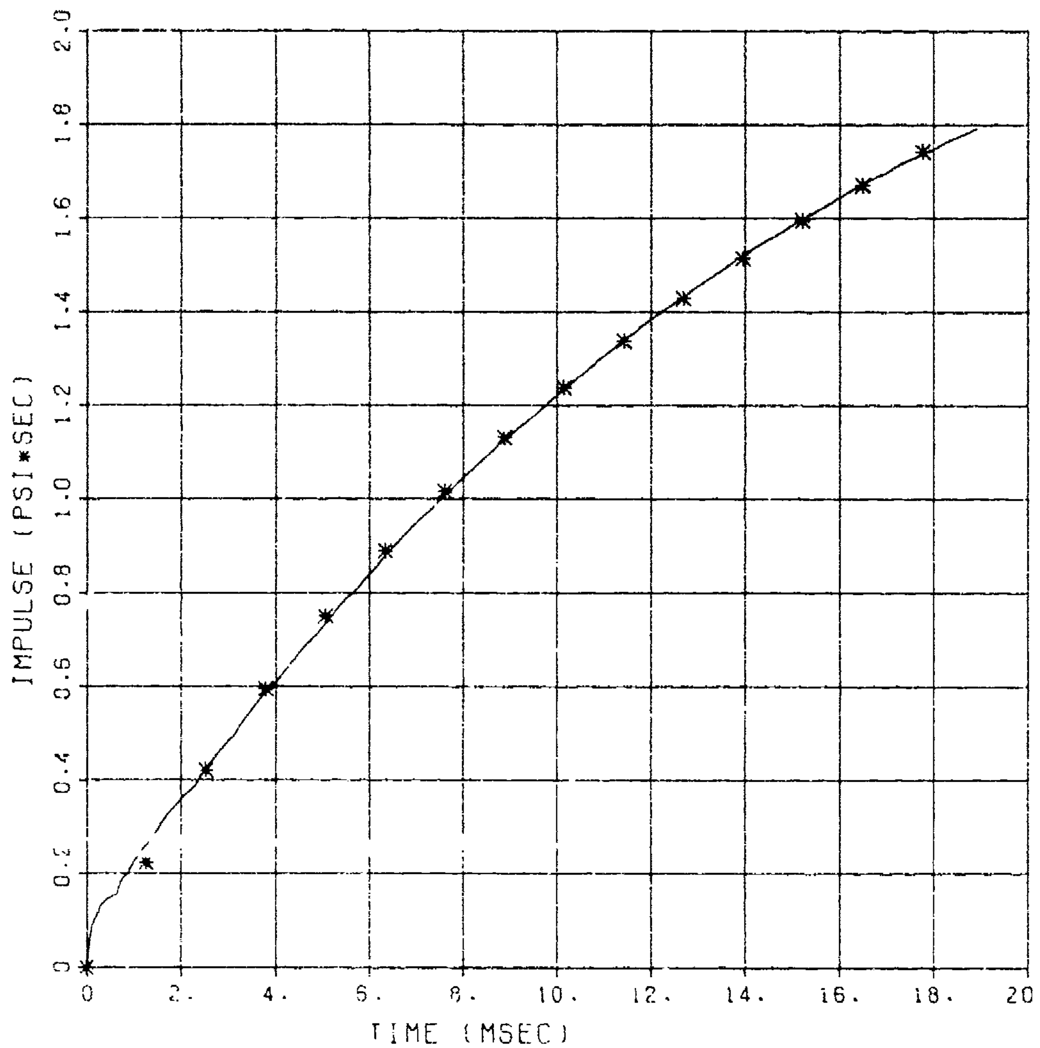
IMPULSE COMPARISON
FEMA YIELD EFFECTS 2
BP-2
SPEICHER-BRODE
W(KT) = 1.838
P(PSI) =206.
HOBF(KFT) = 0.
09/24/84 3544A



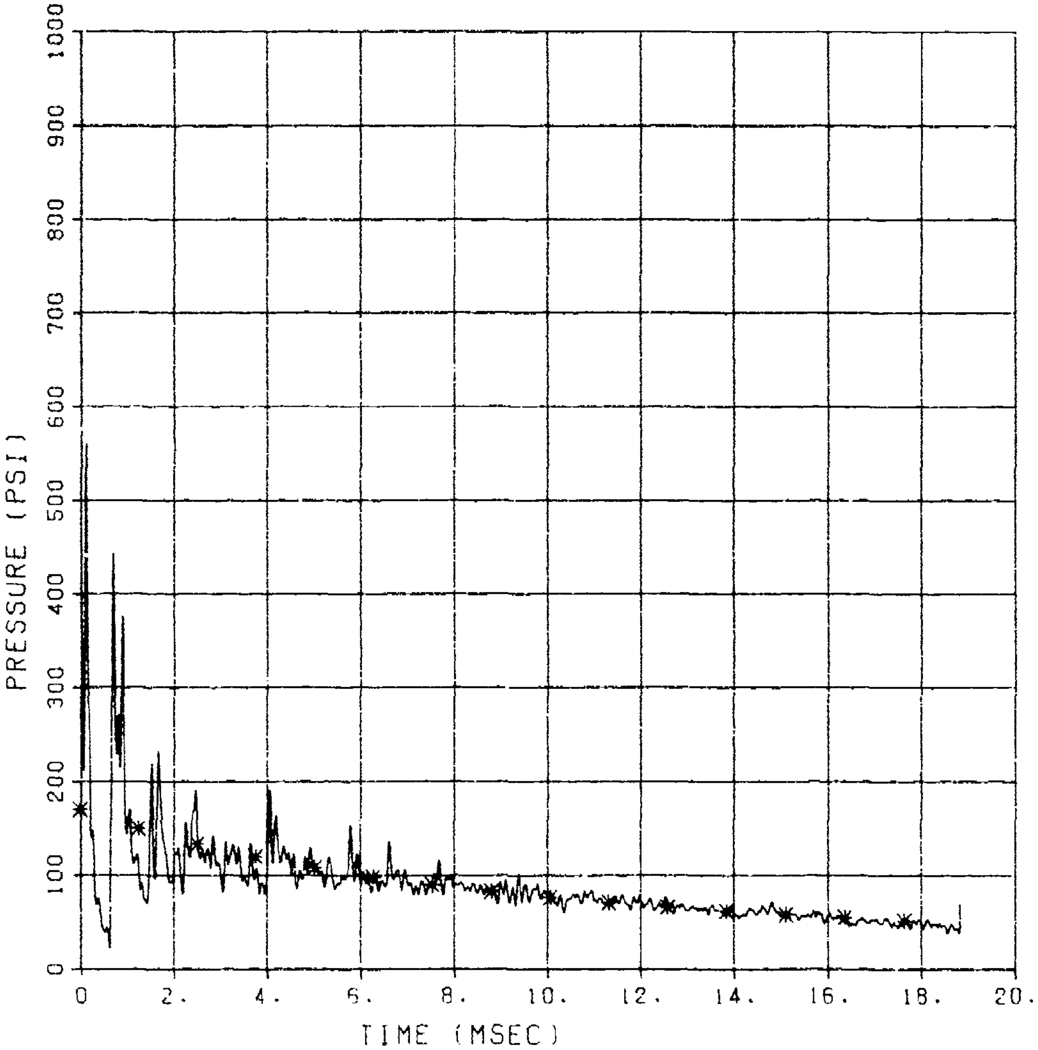
PRESSURE COMPARISON
FEMA YIELD EFFECTS 2
BP-3
SPEICHER-BRODE
W(KT) = 2.766
P(PSI) =189.
HOBF(KFT) = 0.
09/24/84 3544A



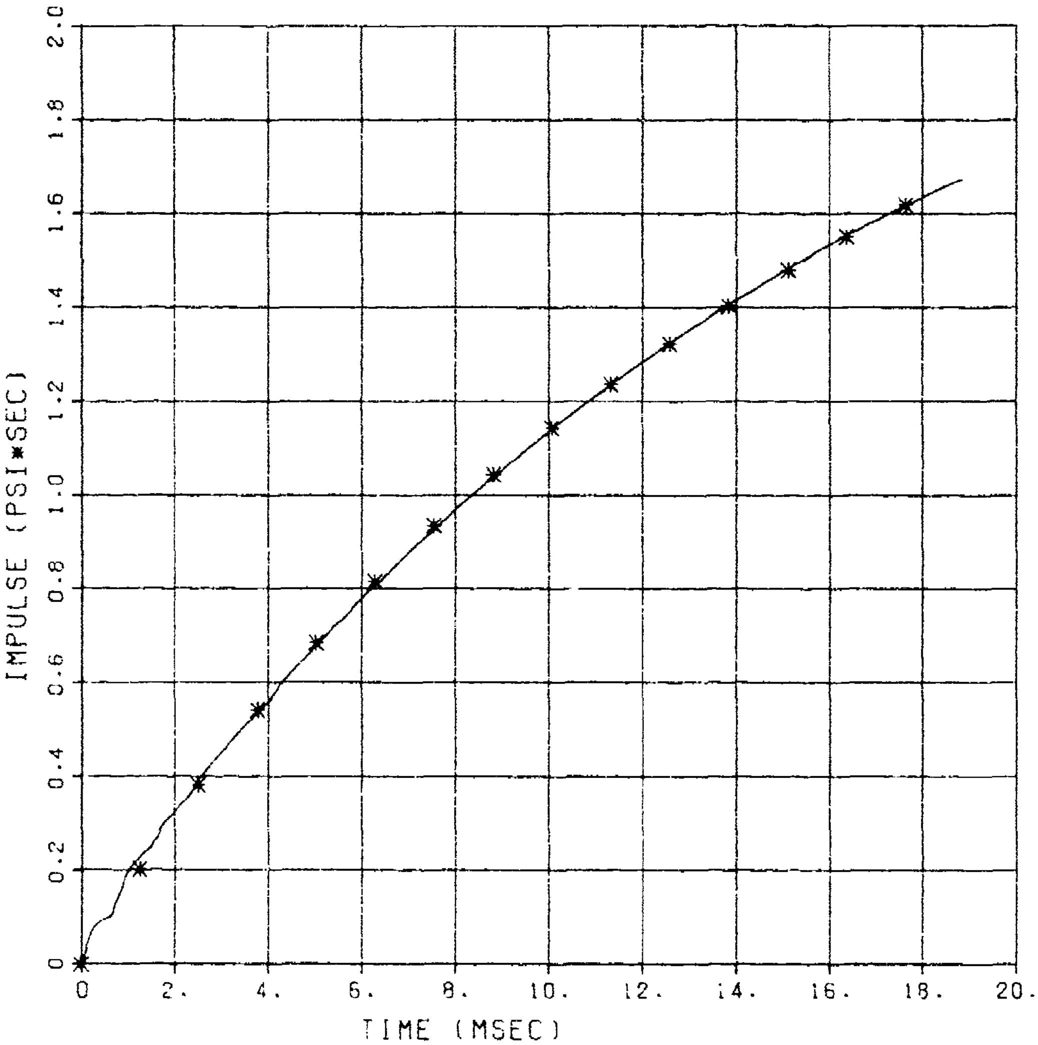
IMPULSE COMPARISON
FEMA YIELD EFFECTS 2
BP-3
SPEICHER-BRODE
W(KT) = 2.766
P(PSI) =189.
HOBF(KFT) = 0.
09/24/84 3544A



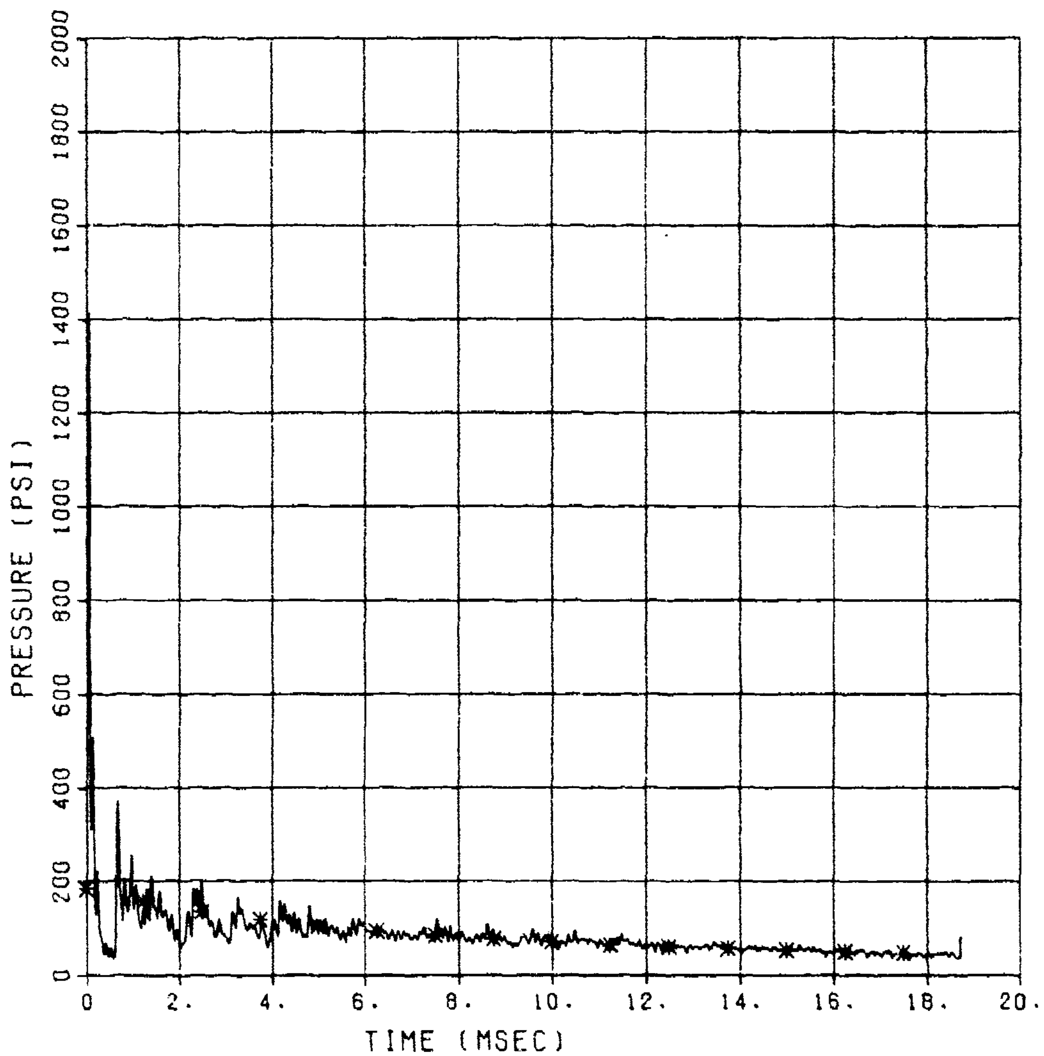
PRESSURE COMPARISON
FEMA YIELD EFFECTS 2
BP-5
SPEICHER-BRODE
W(KT) = 2.872
P(PSI) =171.
HOBF(KFT) = 0.
09/24/84 3544A



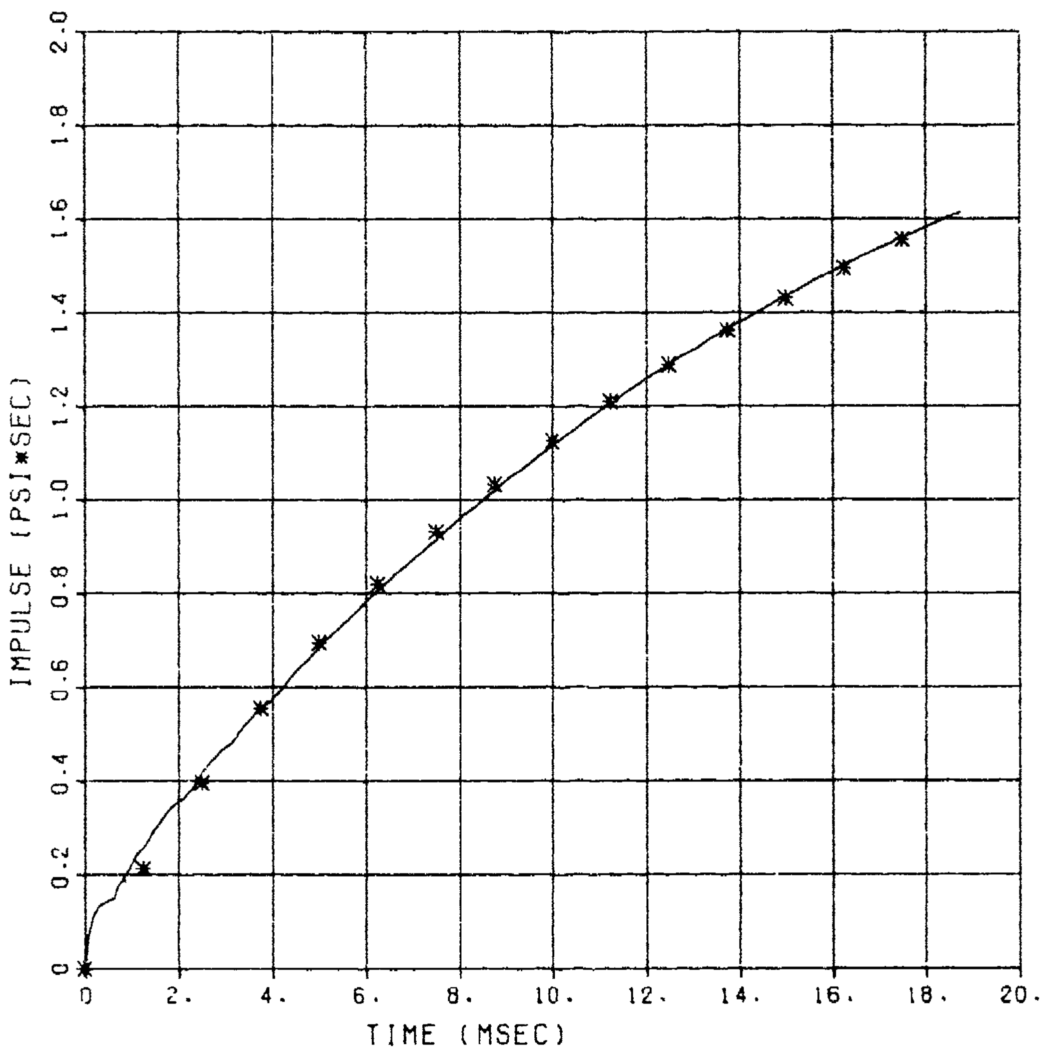
IMPULSE COMPARISON
FEMA YIELD EFFECTS 2
BP-5
SPEICHER-BRODE
W(KT) = 2.872
P(PSI) =171.
HOBF(KFT) = 0.
09/24/84 3544A



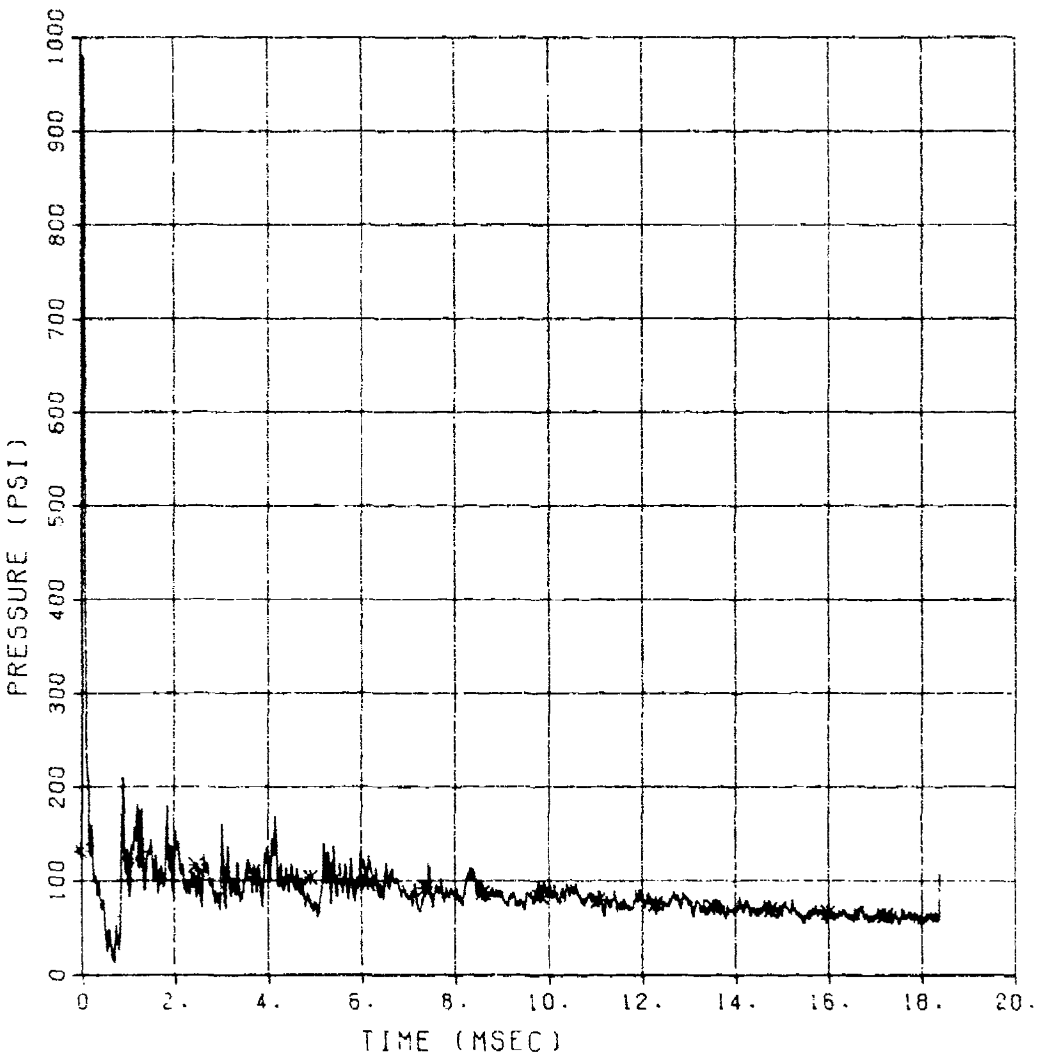
PRESSURE COMPARISON
FEMA YIELD EFFECTS 2
BP-6
SPEICHER-BRODE
W(KT) = 1.550
P(PSI) =185.
HOBF(KFT) = 0.
09/24/84 3544A



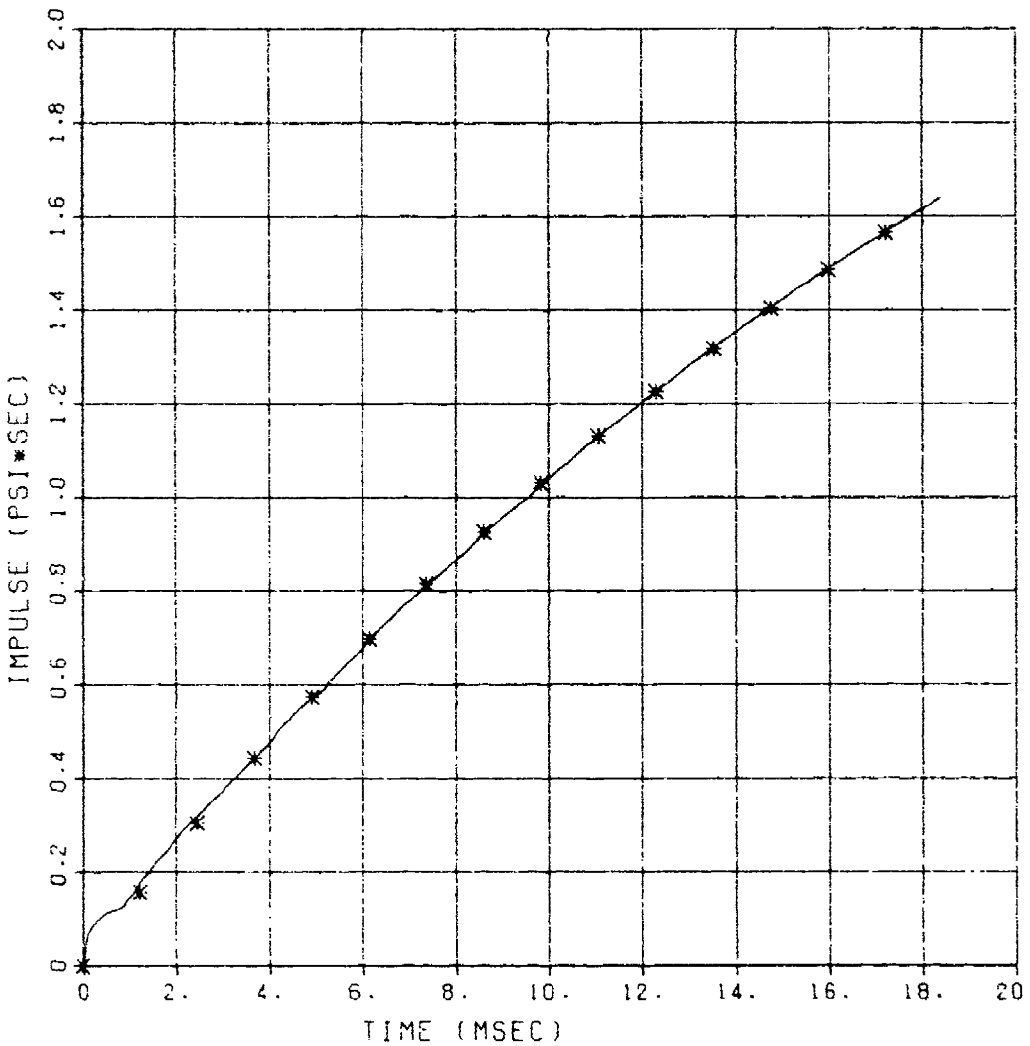
IMPULSE COMPARISON
FEMA YIELD EFFECTS 2
BP-6
SPEICHER-BRODE
W(KT) = 1.550
P(PSI) =185.
HOBF(KFT) = 0.
09/24/84 3544A



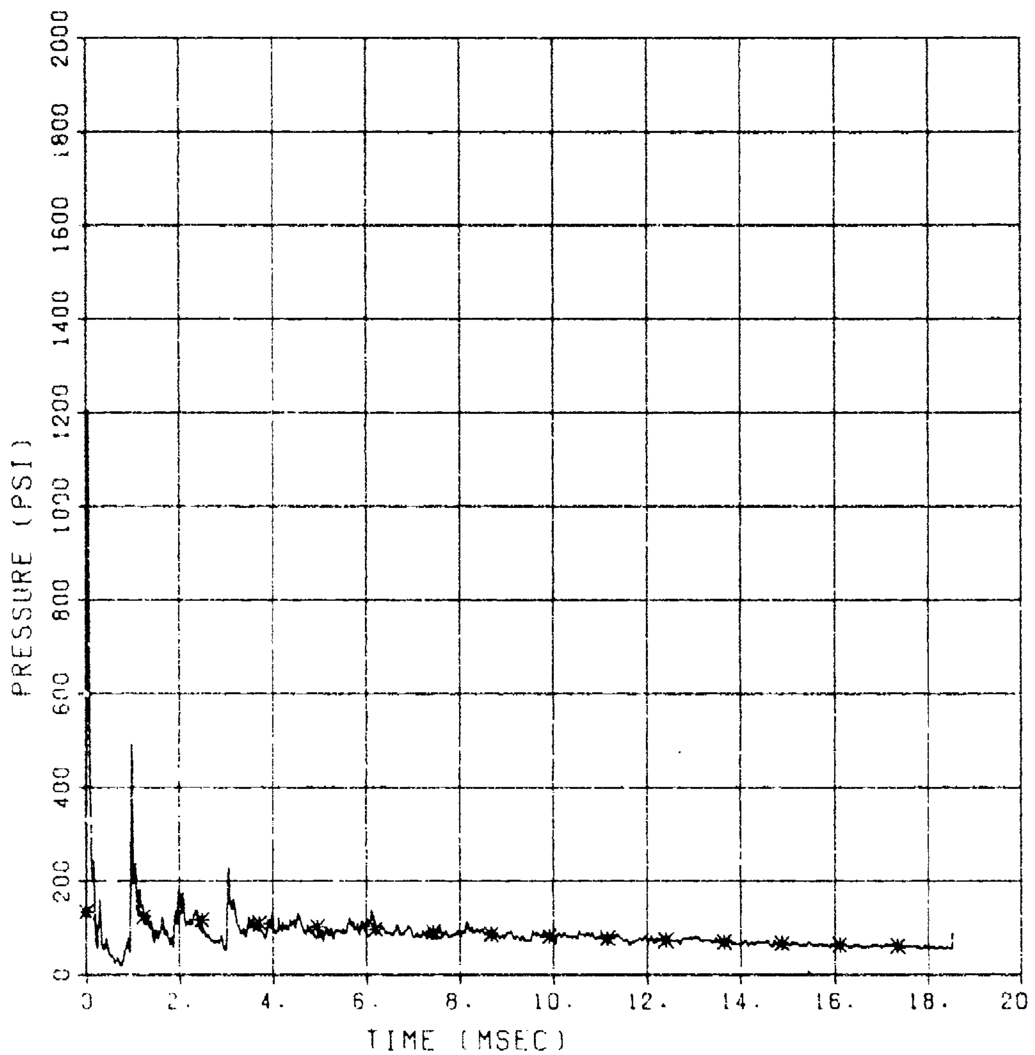
PRESSURE COMPARISON
FEMA YIELD EFFECTS 3
BP-1
SPEICHER-BRODE
W(KT) = 10.704
P(PSI) =132.
HOBF(KFT) = 0.
10/03/84 1238C



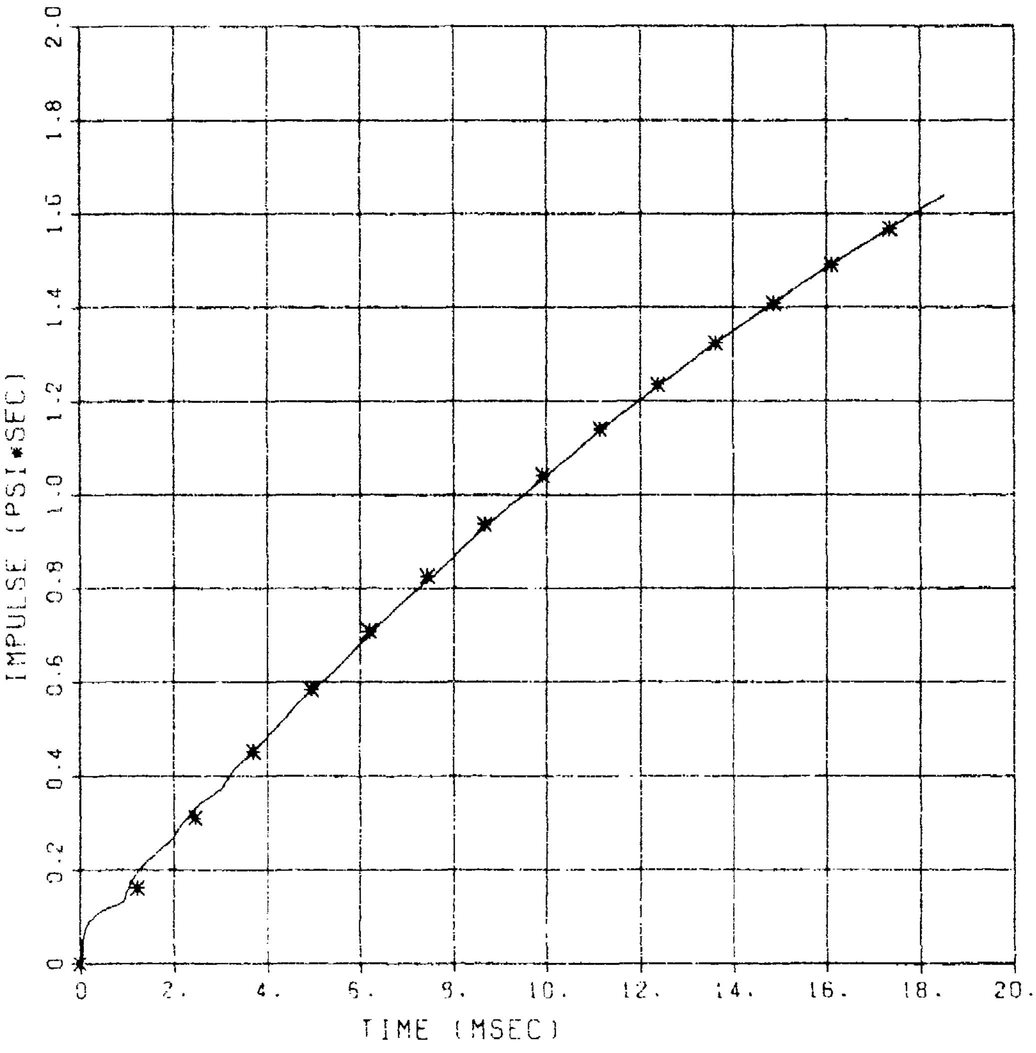
IMPULSE COMPARISON
FEMA YIELD EFFECTS 3
BP-1
SPEICHER-BRODE
W(KT) = 10.704
P(PSI) =132.
HOBF(KFT) = 0.
10/03/84 1238C



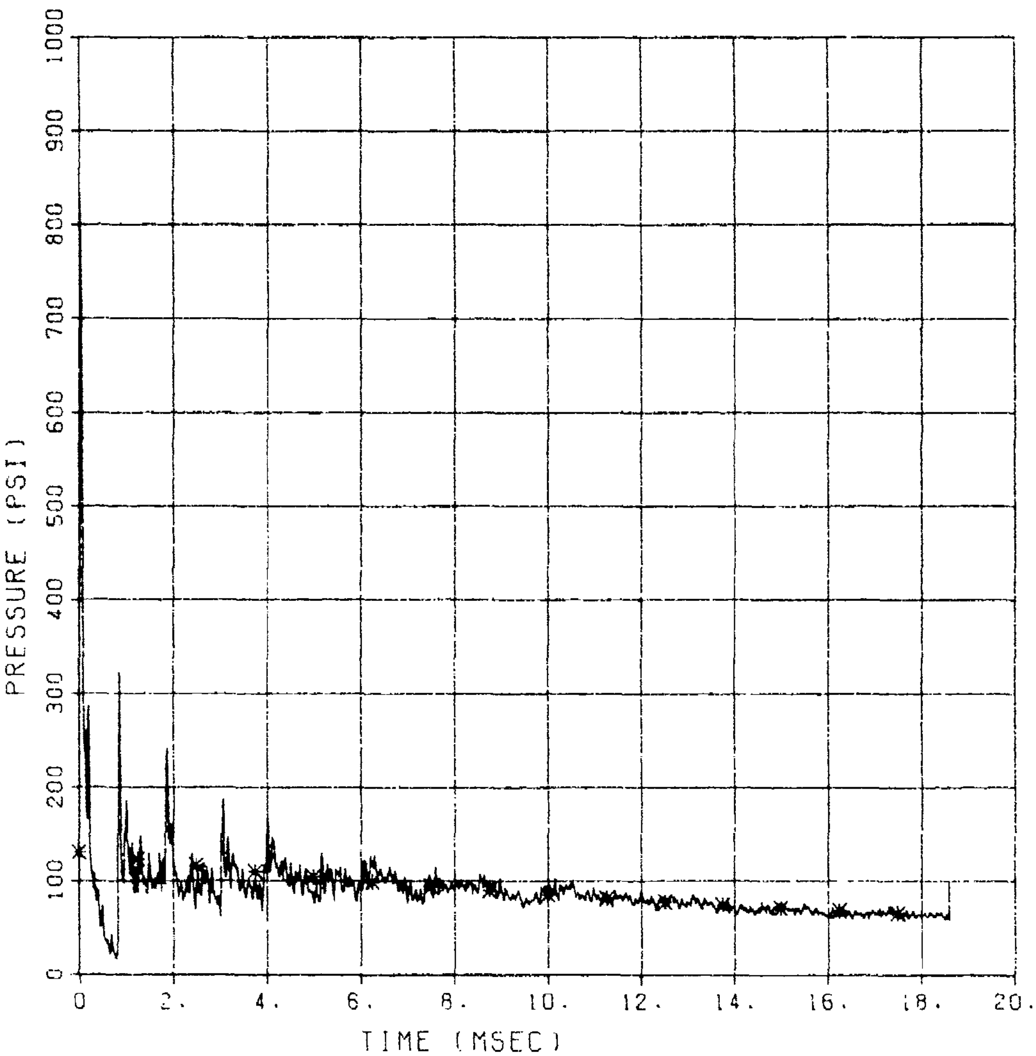
PRESSURE COMPARISON
FEMA YIELD EFFECTS 3
BP-2
SPEICHER-BRODE
W(KT) = 9.160
P(PSI) =134.
HOBF(KFT) = 0.
10/03/84 1238C



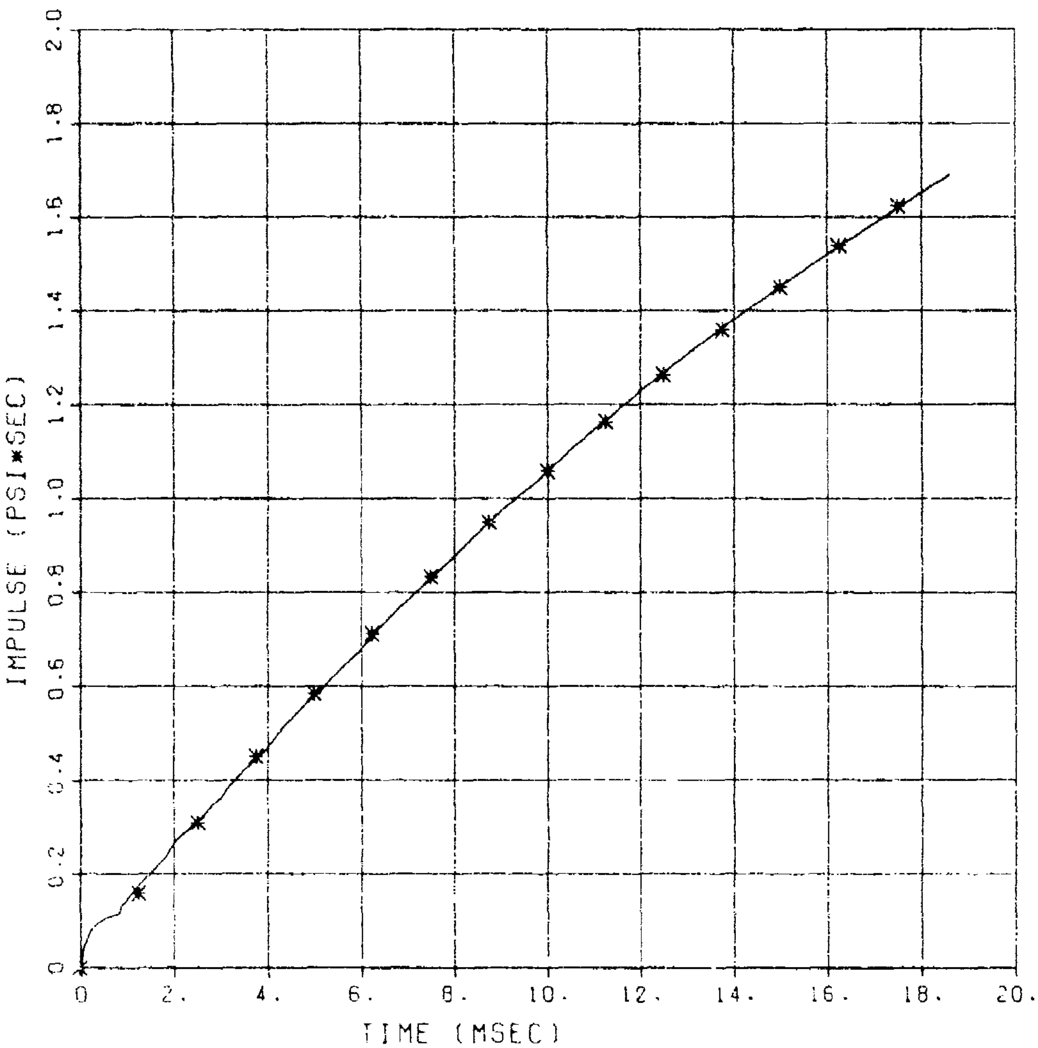
IMPULSE COMPARISON
FEMA YIELD EFFECTS 3
BP-2
SPEICHER-BRODE
W(KT) = 9.160
P(PSI) =134.
HOBF(KFT) = 0.
10/03/84 1238C



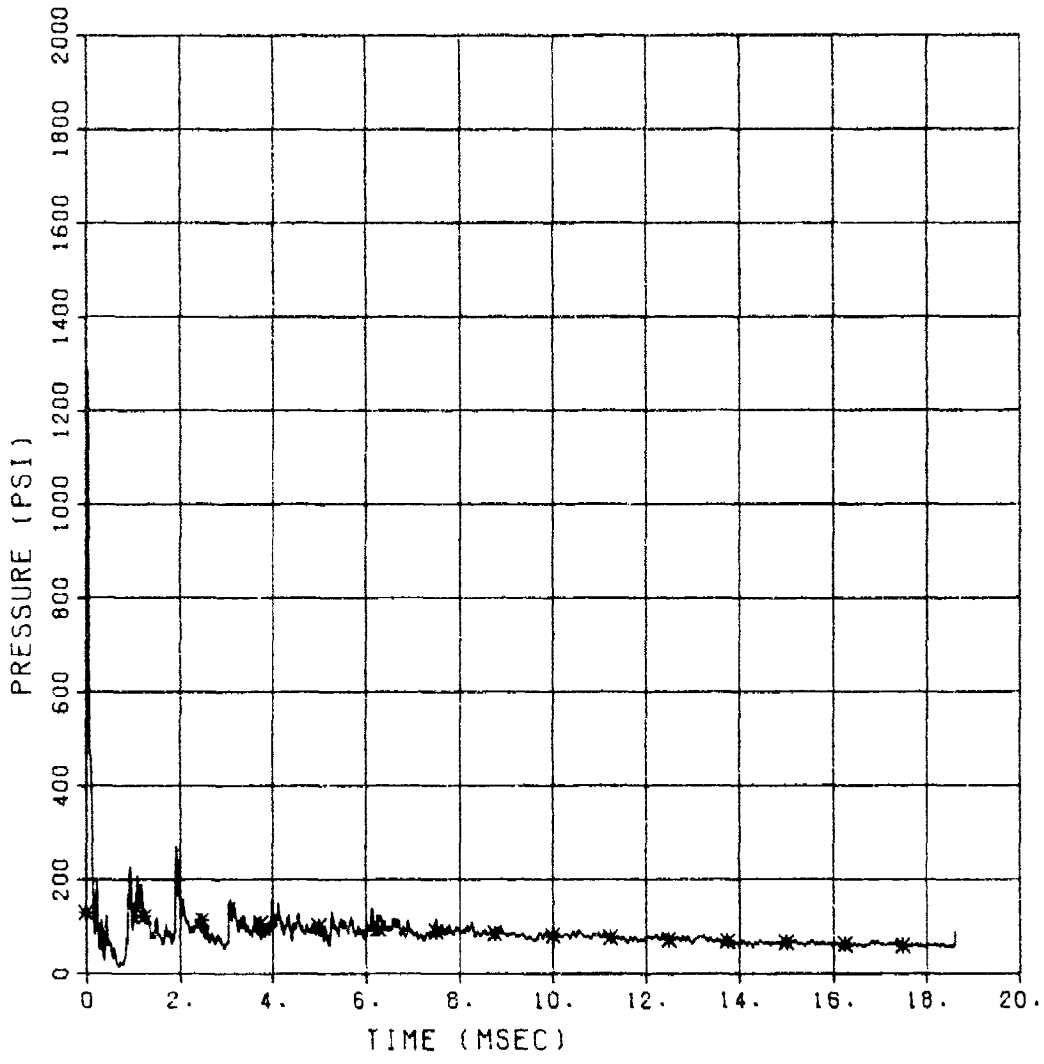
PRESSURE COMPARISON
FEMA YIELD EFFECTS 3
BP-3
SPEICHER-BRODE
W(KT) = 14.499
P(PSI) =131.
HOBF(KFT) = 0.
10/03/84 1238C



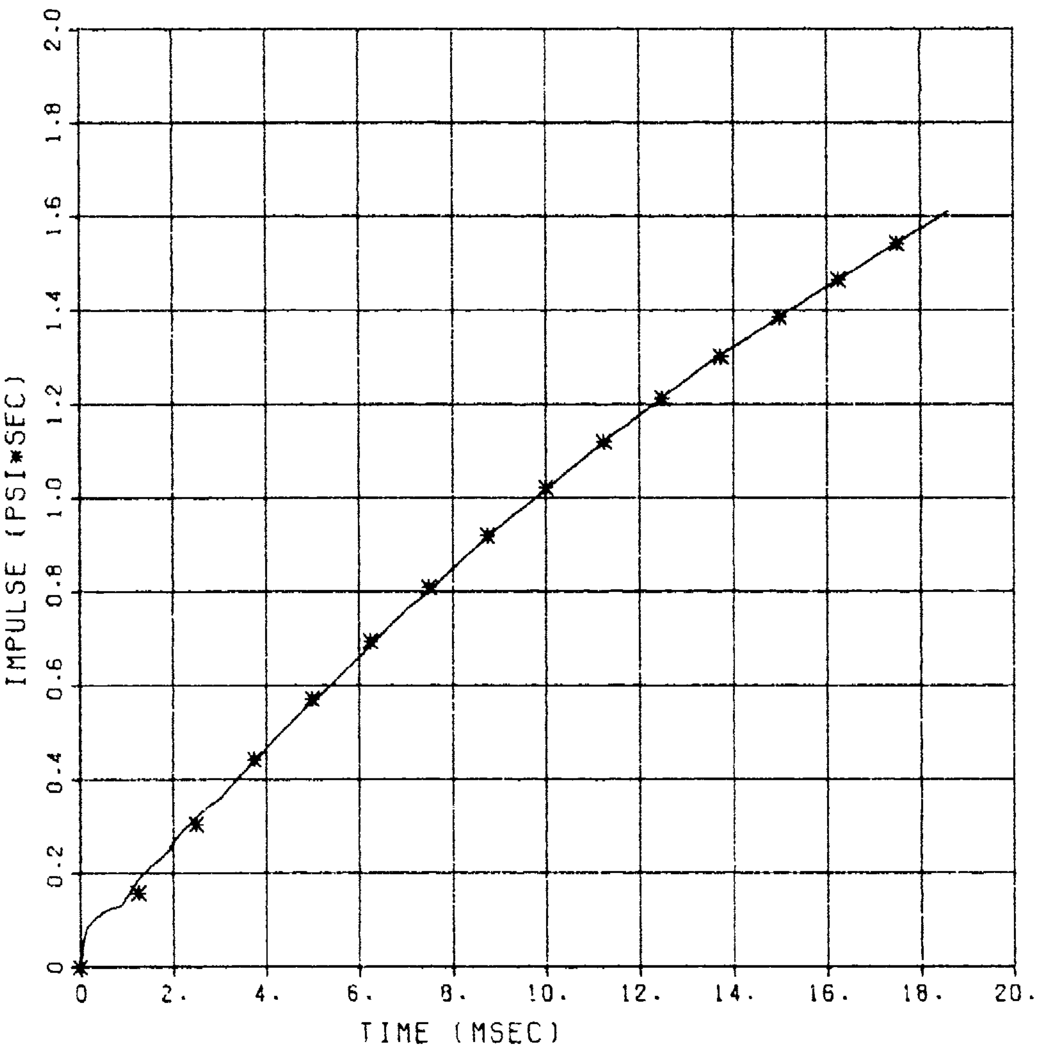
IMPULSE COMPARISON
FEMA YIELD EFFECTS 3
BP-3
SPEICHER-BRODE
W(KT) = 14.499
P(PSI) =131.
HOBF(KFT) = 0.
10/03/84 1238C



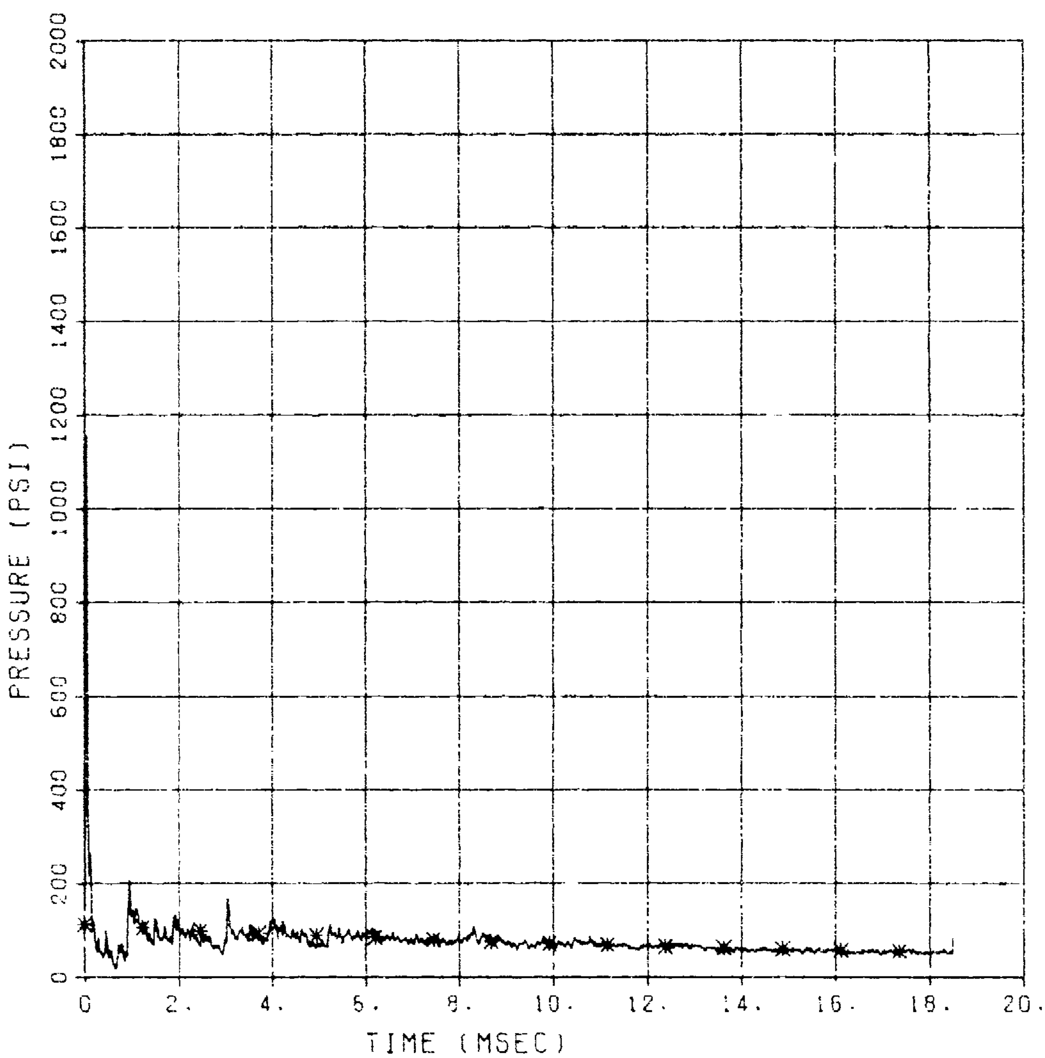
PRESSURE COMPARISON
FEMA YIELD EFFECTS 3
BP-4
SPEICHER-BRODE
W(KT) = 9.249
P(PSI) =130.
HOBF(KFT) = 0.
10/03/84 1238C



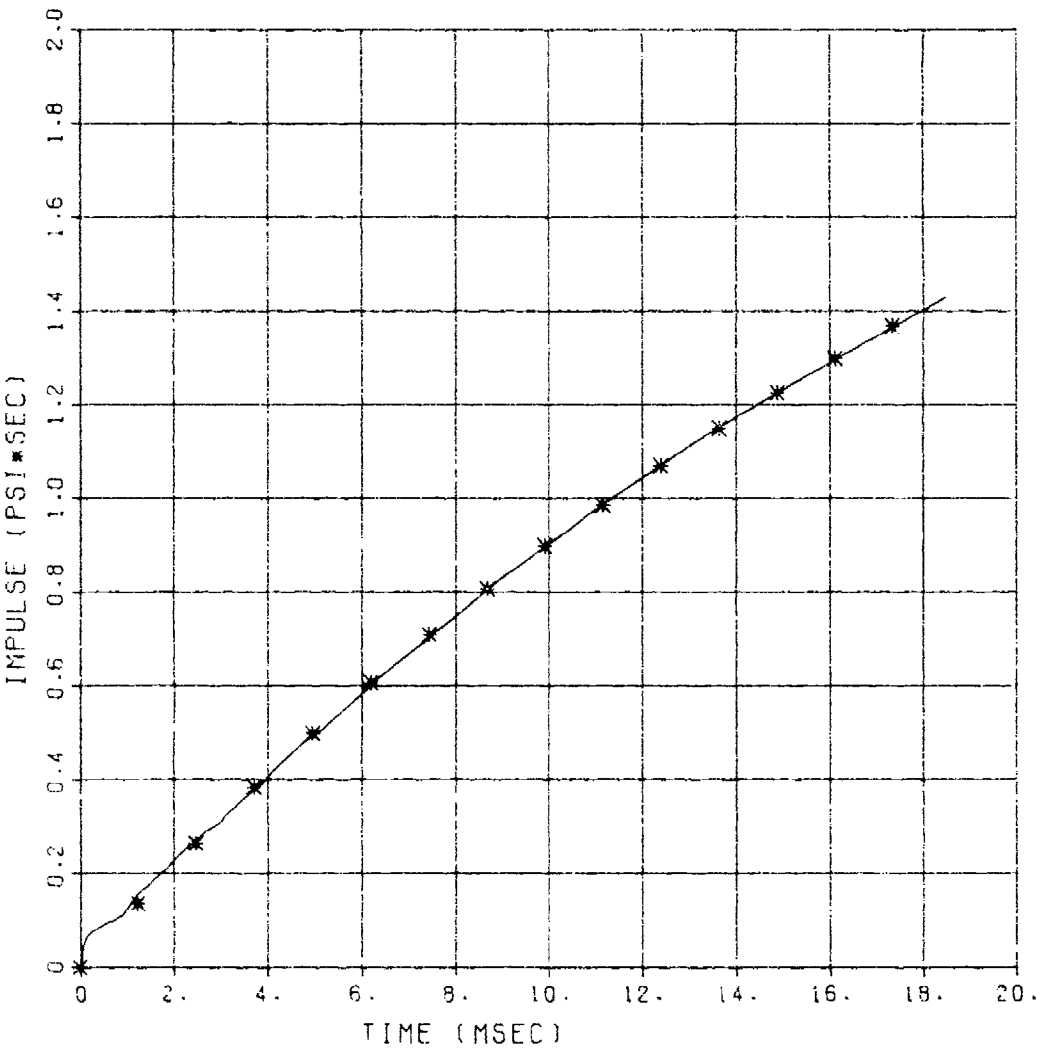
IMPULSE COMPARISON
FEMA YIELD EFFECTS 3
BP-4
SPEICHER-BRODE
W(KT) = 9.249
P(PSI) =130.
HOBF(KFT) = 0.
10/03/84 1238C



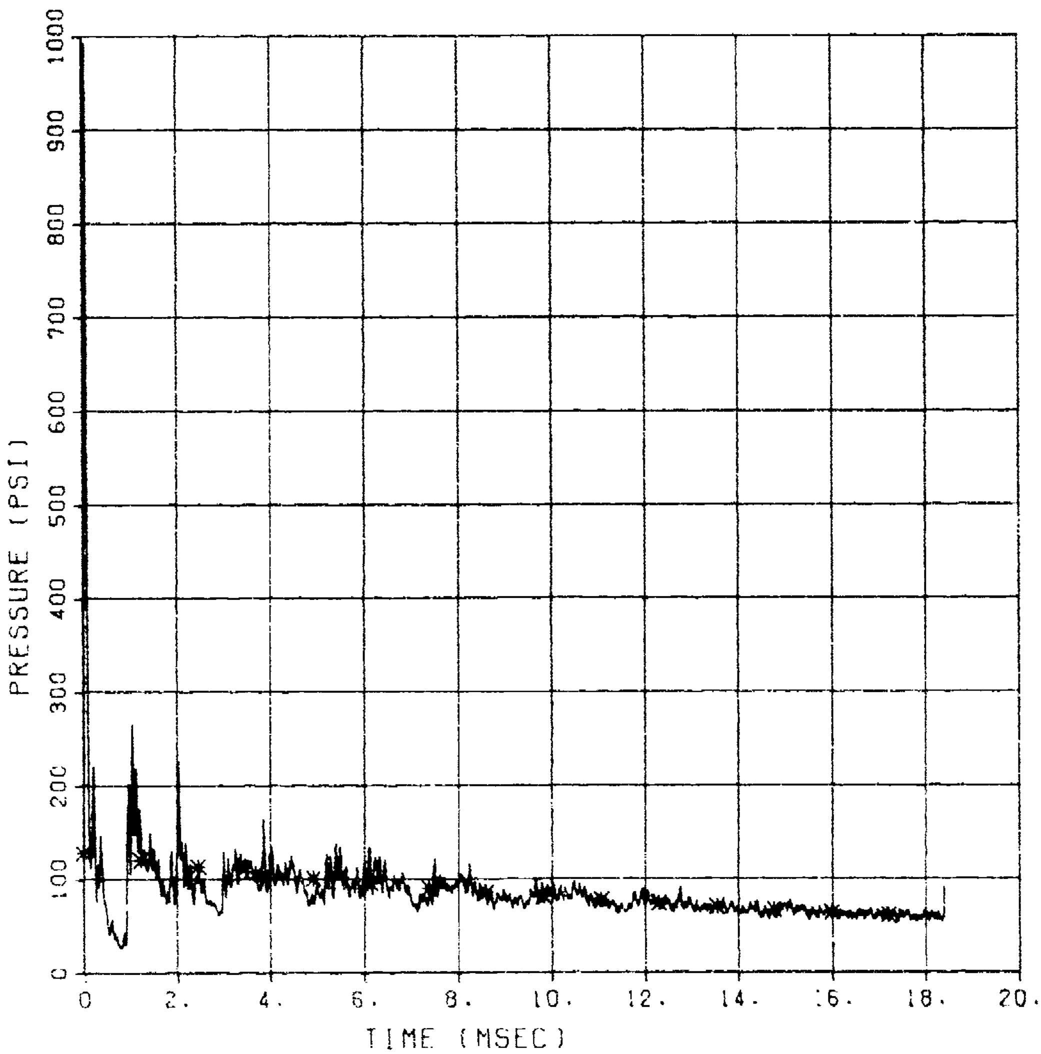
PRESSURE COMPARISON
FEMA YIELD EFFECTS 3
BP-5
SPEICHER-BRODE
W(KT) = 7.279
P(PSI) =113.
HOBF(KFT) = 0.
10/03/84 1238C



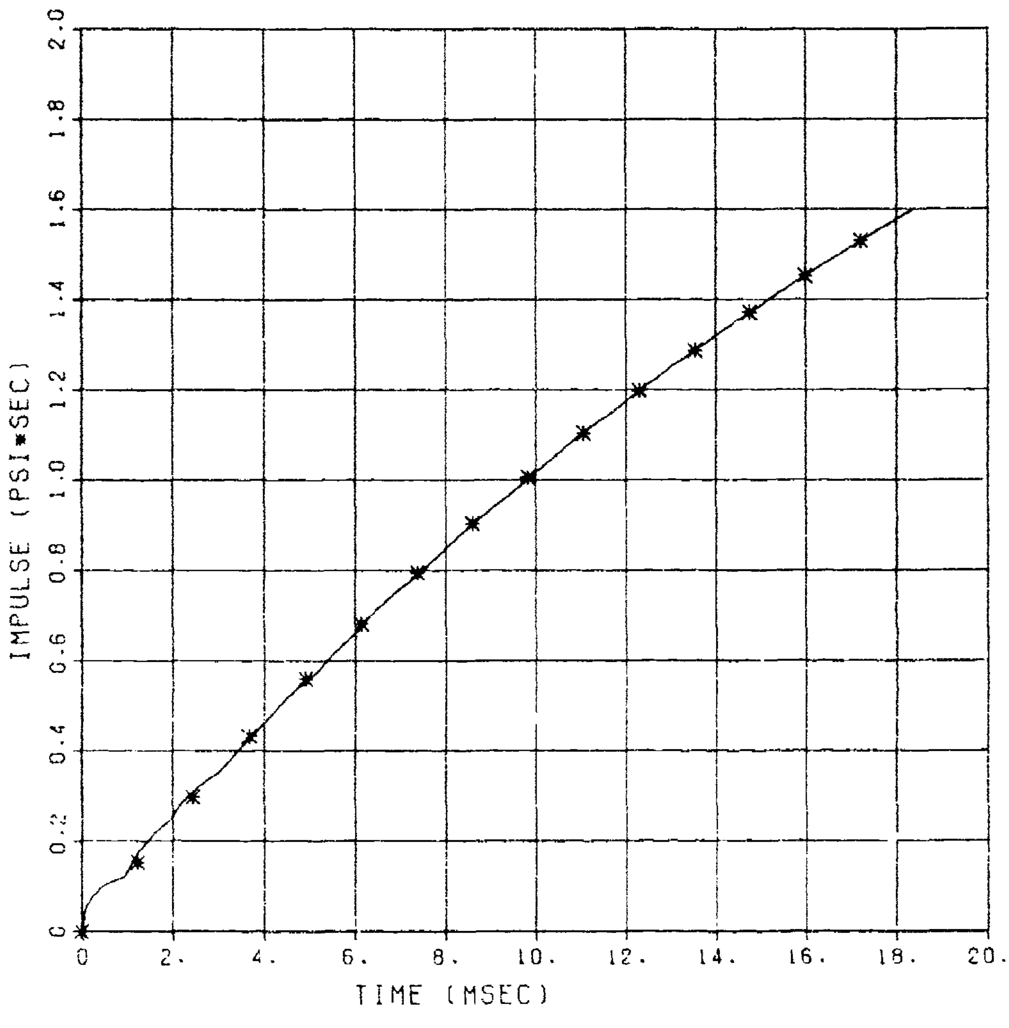
IMPULSE COMPARISON
FEMA YIELD EFFECTS 3
BP-5
SPEICHER-BRODE
W(KT) = 7.279
P(PSI) =113.
HOBF(KFT) = 0.
10/03/84 1238C



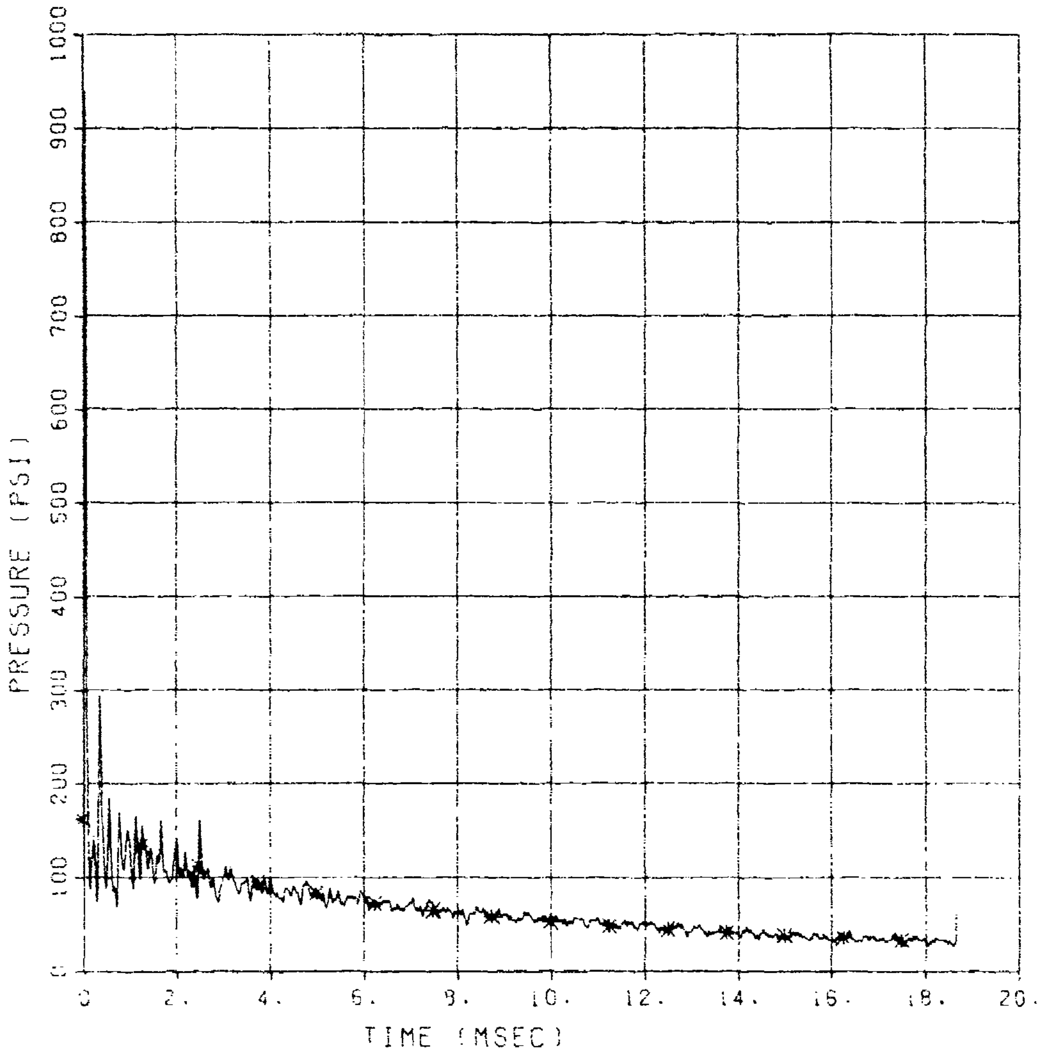
PRESSURE COMPARISON
FEMA YIELD EFFECTS 3
BP-6
SPEICHER-BRODE
W(KT) = 10.228
P(PSI) =128.
HOBF(KFT) = 0.
10/03/84 1238C



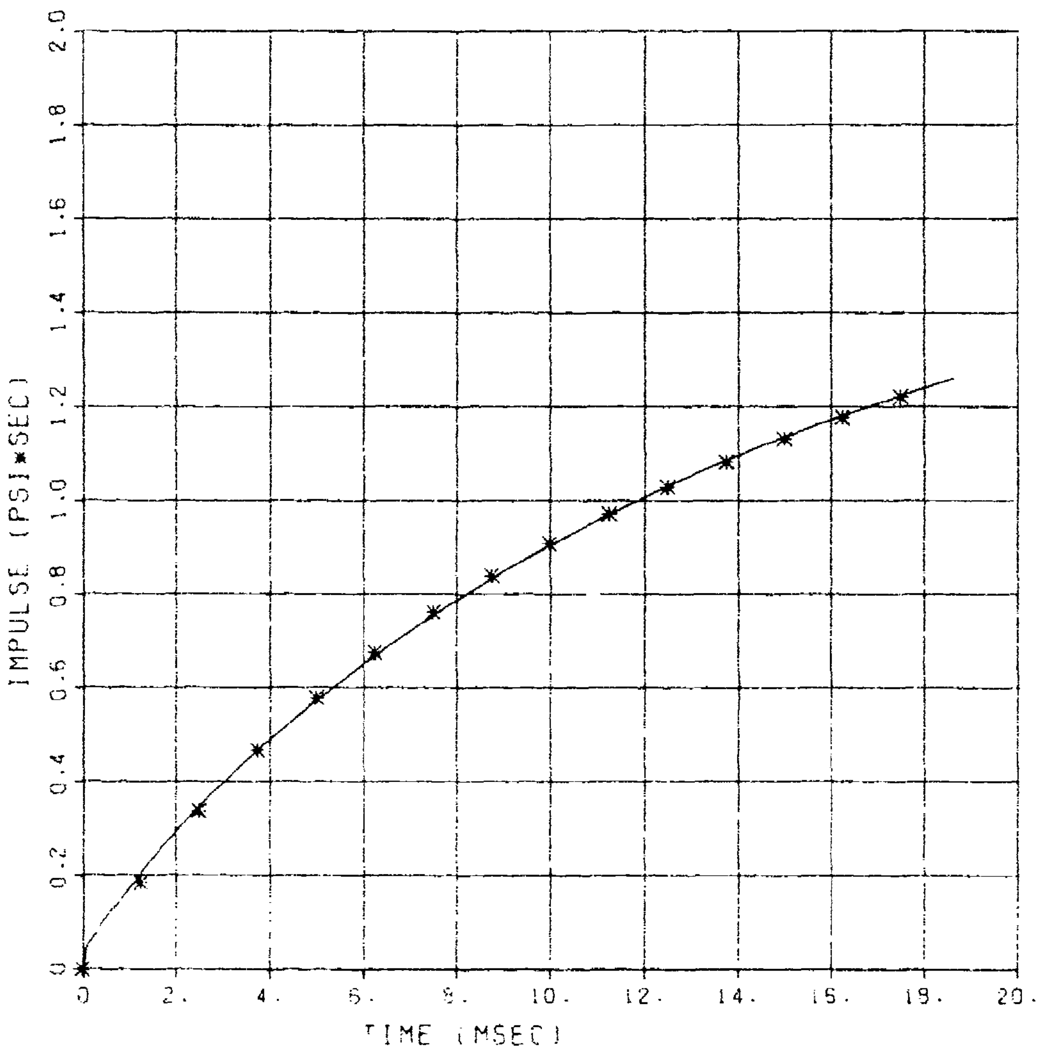
IMPULSE COMPARISON
FEMA YIELD EFFECTS 3
BP-6
SPEICHER-BRODE
W(KT) = 10.228
P(PSI) =128.
HOBF(KFT) = 0.
10/03/84 1238C



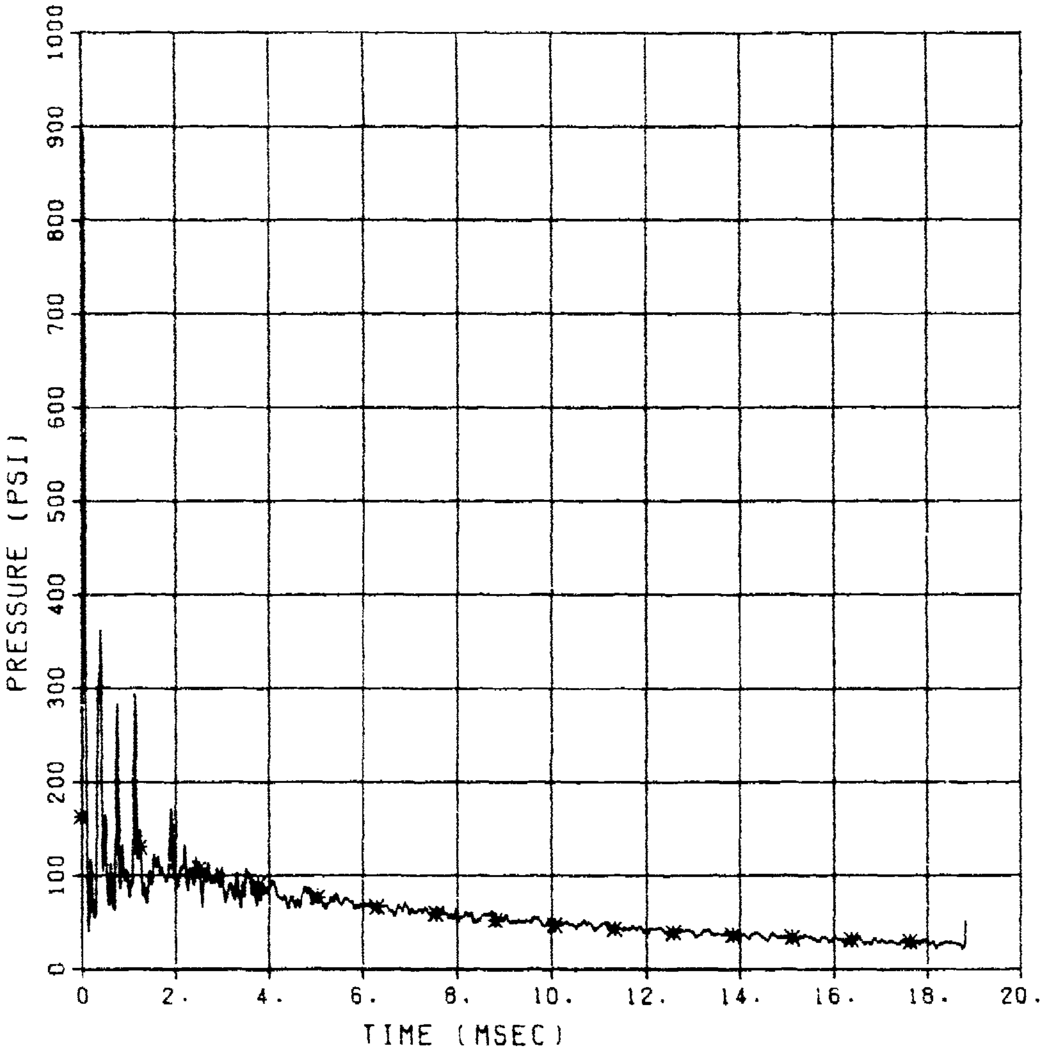
PRESSURE COMPARISON
FEMA YIELD EFFECTS 4
BP-1
SPEICHER-BRODE
W(KT) = 0.622
P(PSI) =163.
HOBF(KFT) = 0.
10/17/84 2060C



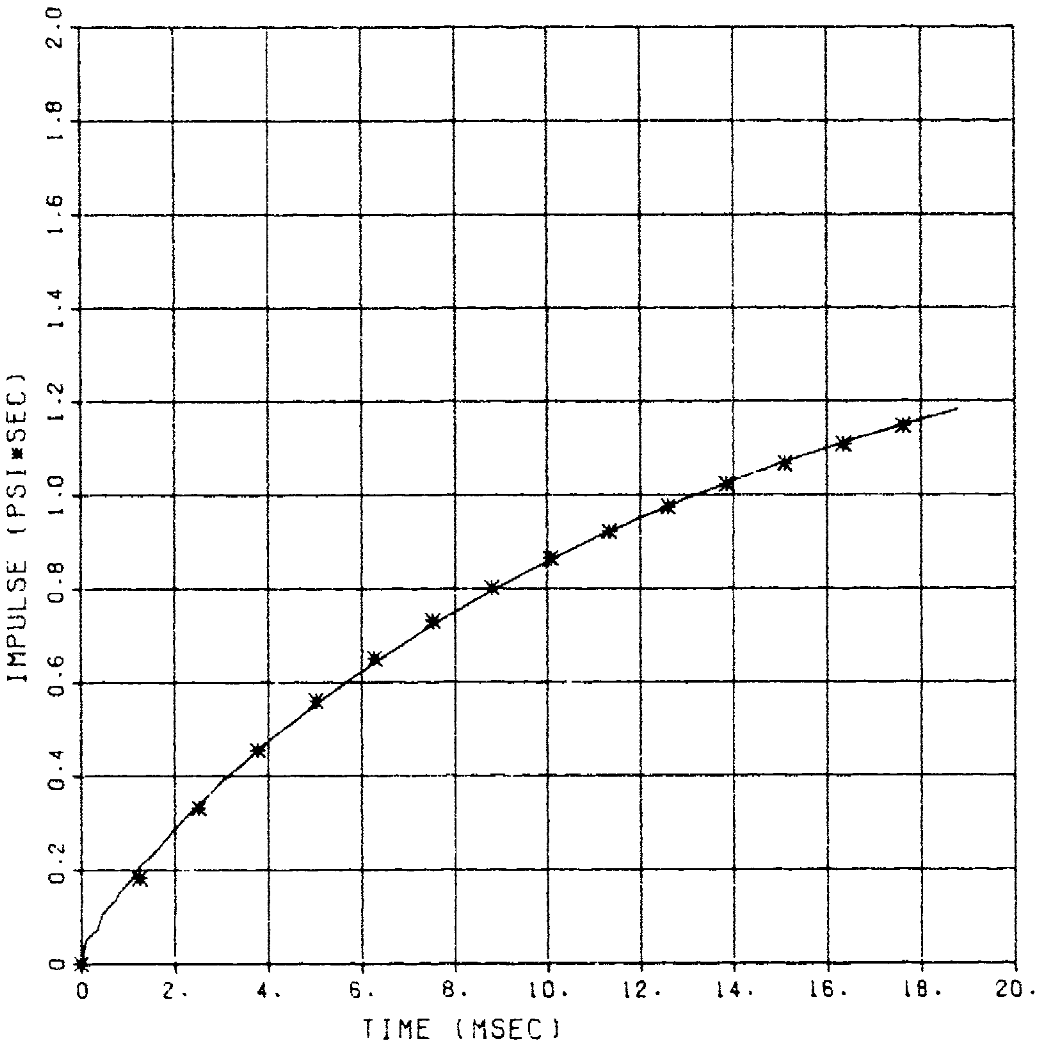
IMPULSE COMPARISON
FEMA YIELD EFFECTS 4
BP-1
SPEICHER-BRODE
W(KT) = 0.622
P(PSI) =153.
HOBF(KFT) = 0.
10/17/84 2060C



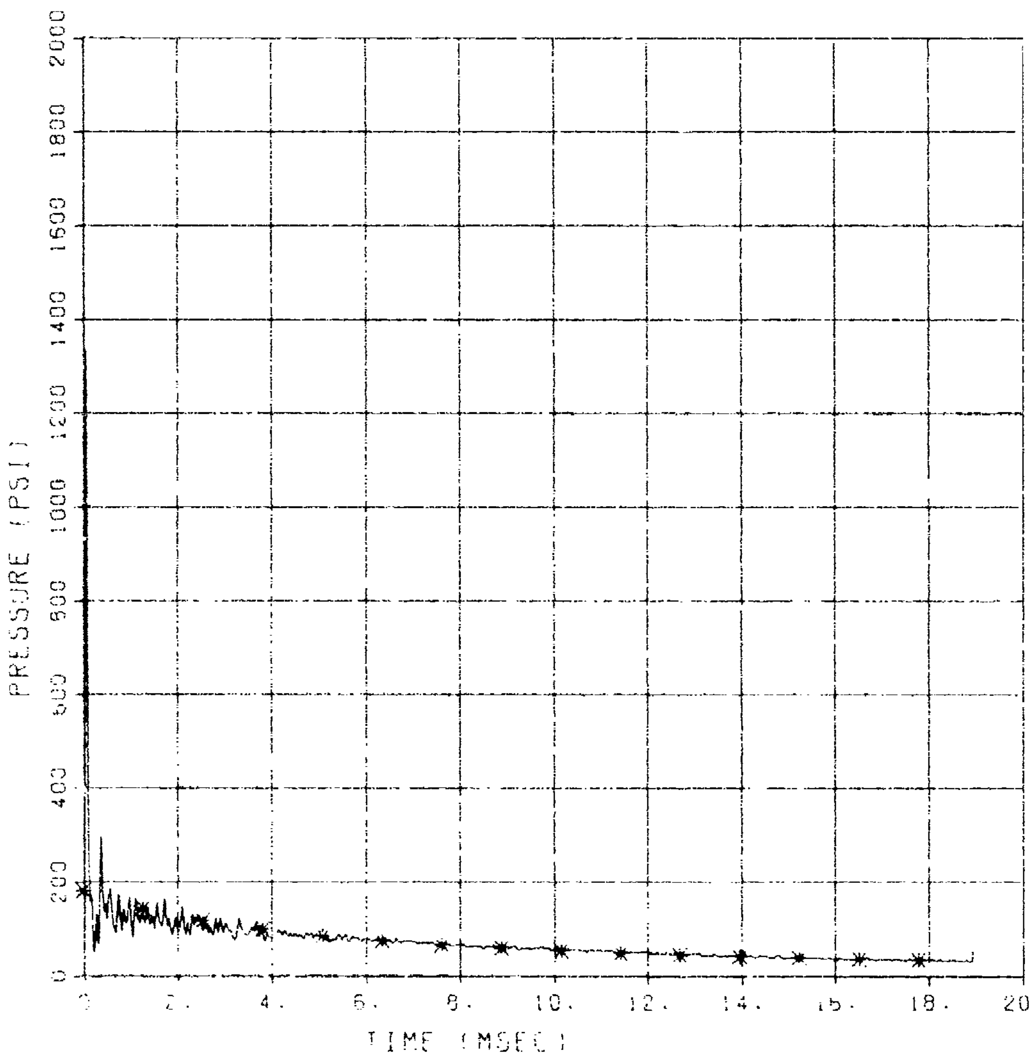
PRESSURE COMPARISON
FEMA YIELD EFFECTS 4
BP-2
SPEICHER-BRODE
W(KT) = 0.429
P(PSI) =163.
HOBF(KFT) = 0.
10/17/84 2060C



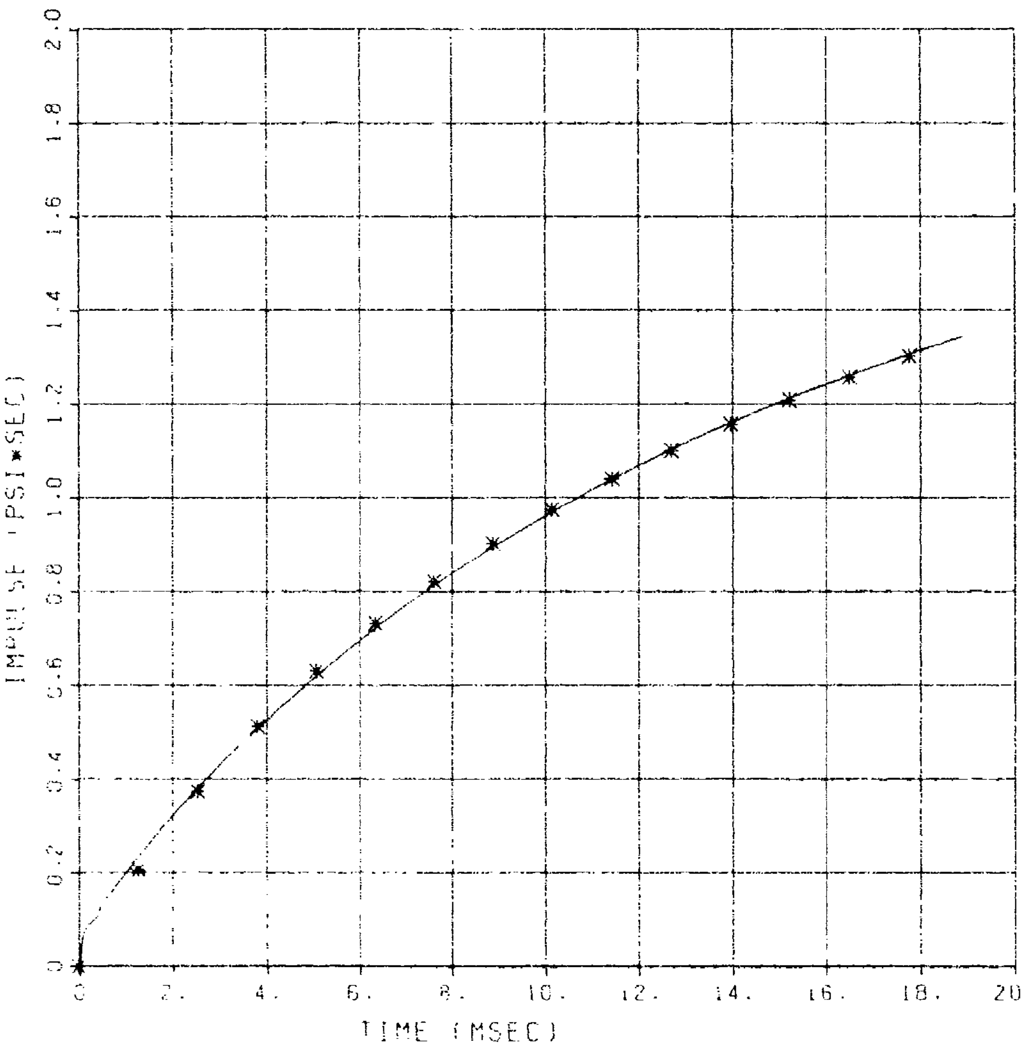
IMPULSE COMPARISON
FEMA YIELD EFFECTS 4
BP-2
SPEICHER-BRODE
W(KT) = 0.429
P(PSI) =163.
HOBF(KFT) = 0.
10/17/84 2060C



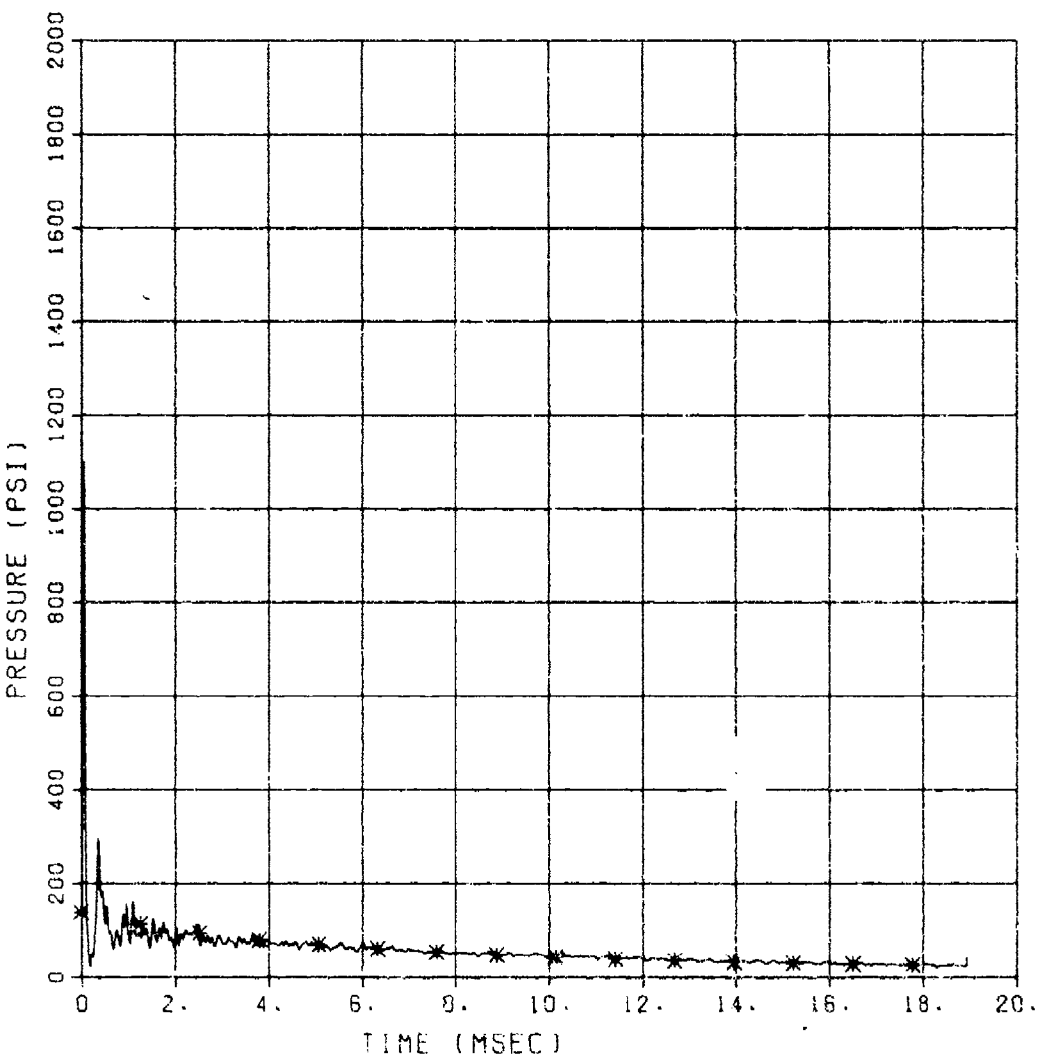
PRESSURE COMPARISON
FEMA YIELD EFFECTS 4
BF-3
SPEICHER-BRODE
W(KT) = 0.555
P(PSI) =181.
HOB(KFT) = 0.
10/17/84 2060C



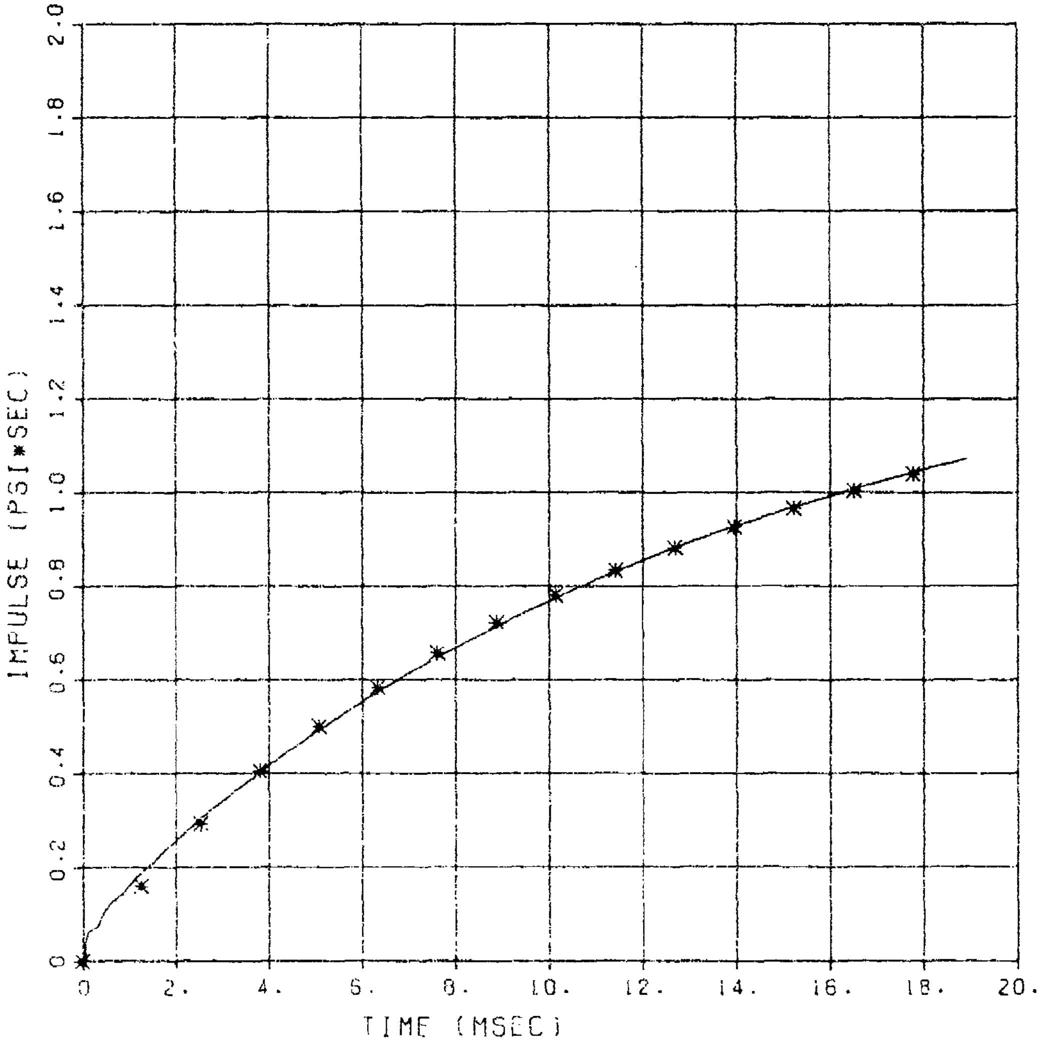
IMPULSE COMPARISON
FEMA YIELD EFFECTS 4
BP-3
SPEICHER-BRODE
W(KT) = 0.555
P(PSI) =191.
HOBF(KFT) = 0.
10/17/84 2060C



PRESSURE COMPARISON
FEMA YIELD EFFECTS 4
BP-4
SPEICHER-BRODE
W(KT) = 0.420
P(PSI) =139.
HOBF(KFT) = 0.
10/17/84 2060C



IMPULSE COMPARISON
FEMA YIELD EFFECTS 4
BP-4
SPEICHER-BRODE
W(KT) = 0.420
P(PSI) =139.
HOBF(KFT) = 0.
10/17/84 2060C



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YIELD EFFECTS ON THE RESPONSE OF A BURIED BLAST SHELTER. Unclassified, US Army Engineer Waterways Experiment Station, April 1986, 273 pp.

The Federal Emergency Management Agency has tasked the US Army Engineer Division, Huntsville, to design a 100-man Keyworker blast shelter. The shelter has been designed to resist a peak overpressure of 50 psi from a 1-MT nuclear weapon. Two configurations have been considered: an underground shelter buried under 4 feet of backfill and an aboveground shelter enclosed in a soil berm.

A prototype buried shelter was tested in the Defense Nuclear Agency high-explosive event called MINOR SCALE in June 1985, at White Sands Missile Range, N. Mex. The MINOR SCALE Event simulated an 8-KT nuclear surface burst. Prior to the MINOR SCALE Event, the US Army Engineer Waterways Experiment Station conducted a series of tests to investigate the effects of variations in weapon yield on structural response of the Keyworker shelter. Calculations using the VSHS computer program were compared to test results.

Four 1/4-scale structural models were exposed to high-explosive tests simulating overpressures from approximately 1/2- to 10-KT nuclear bursts. Based on test results, the VSHS program appears to be an accurate method for predicting the variations in yield and overpressure required to cause a specified level of structural damage. The test results indicated that the prototype structure should be placed near the 75-psi peak overpressure level in the MINOR SCALE Event to incur the same damage as from a 1-MT surface burst.

The test series also investigated the use of shear stirrups in the walls of the Keyworker shelter. Although wall stirrups may not be required to prevent failure at the 50-psi level, including them ensures that the wall will not fail prematurely at slightly higher overpressures.

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